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PROCEEDINGS

SANDUSKY RIVER BASIN SYMPOSIUM

MAY 2 – 3, 1975
TIFFIN, OHIO

Co-sponsors: Heidelberg College
Bowling Green State University

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The Sandusky River Basin occupies a 1450 square mile area in Northwestern Ohio and has a population of about 140,000. Within the basin, water quality management objectives include both reduction of adverse impacts on Lake Erie and improvement of stream water quality. Management options include: agricultural pollution abatement measures, advanced treatment of municipal wastes, flow augmentation from pumped storage upground reservoirs, improved sewer collection systems and more strict home sewage regulations in rural developments. The publication covers the proceedings of the Sandusky River symposium, which includes 34 papers concerned with planning and improvements.

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Tiffin, Ohio

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PREFACE

The Sandusky River Basin Symposium, held at Heidelberg College in Tiffin, Ohio and jointly sponsored by Heidelberg and Bowling Green State University, brought together more than 150 persons engaged in environmental research, monitoring, and management, both in the Sandusky Basin and from surrounding areas. The program scope and the purpose of the symposium indicated:

> A considerable amount of ecological research and monitoring activity is taking place within the Sandusky River and Bay areas. The research ranges from studies of the geology, hydrology, and soils of the basin and bay to measurements of the biological and chemical characteristics of the river and bay. In this conference, the individuals who are involved in the entire scope of the above research efforts, as well as those involved with water quality management within the basin, will present their research results and current management practices.
>
> The purpose of this conference is to provide an opportunity for the scientists engaged in ecological research and those engaged in management to exchange detailed information that will aid both in future work. The conference should also provide useful information to individuals working in other river basin studies and anyone interested in the relationships between ecosystem research and river basin management.

The sumposium was successful in attaining many of these objectives, and the diversity and detail of environment-related studies underway in the Sandusky Basin and Bay areas was impressive. The historical perspectives of this region, as brought forth in papers by Trautman, Forsyth, and Stuckey, created a useful foundation. The keynote address by Cummins, extending stream ecosystem theory to larger rivers, had significant impact on both ecosystem concepts and management applications. The contributions of personnel in governmental agencies provided an overview of programs within which environmental planning and management take place.

The program of the symposium has been reproduced in the table of contents. The proceedings differ from the symposium in that the many excellent color slides, which potentiated the presentations, necessarily have been replaced by tabular data. Both these quantitative and qualitative presentations will aid future studies in this basin and other areas.

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ABSTRACT

INTRODUCTION TO THE SANDUSKY RIVER BASIN

D. B. BAKER

Heidelberg College, Tiffin, Ohio

The Sandusky River Basin occupies a 1450 mi^2 area in Northwestern Ohio and has a population of about 140,000. Approximately 70% of the land is cultivated, 9% pasture land, 9% forest, 6% other rural uses and 6% urban. The river empties into Sandusky Bay, the largest embayment on the southern shore of Lake Erie, and subsequently into the central basin of Lake Erie.

The wooded banks of the Sandusky River and its tributaries provide a corridor of natural vegetation extending throughout the otherwise intensively cultivated landscape. Its scenic value, ecological significance and recreational potential have been recognized through designation and development as an Ohio State Scenic River. The river is also an important water supply for public, industrial, and agricultural use.

Although secondary sewage treatment and chlorination are provided by the major cities, water quality in the stream nevertheless frequently falls below state standards. Water quality problems in the river include: high turbidity and suspended solids; high nutrient concentration and transport; generally high coliform bacterial levels; occasional nuisance level algae blooms and associated excessive diurnal oxygen fluctuations; and a collage of minor insults such as accidental oil or chemical spills and combined sewer overflows.

Within the basin, water quality management objectives include both reduction of adverse impacts on Lake Erie and improvement of stream water quality. Management options include: agricultural pollution abatement measures, advanced treatment of municipal wastes, flow augmentation from pumped storage upground reservoirs, improved sewer collection systems and more strict home sewage regulations in rural developments.

the publication covers the proceedings of the Sandusky River symposium which includes 34 papers which are concerned with planning and implementation

INTRODUCTION TO THE SANDUSKY RIVER BASIN

DAVID B. BAKER

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The Sandusky River Basin occupies a 1,421 square mile area in Northwestern Ohio. According to 1970 census figures, the population of the basin is about 140,000. Approximately one half of the population resides in cities or small towns and one half in rural areas. The locations of major cities in the basin are shown in figure 1.

The dominant land-use within the Sandusky Basin is agriculture. For the four principle counties within the basin (Crawford, Wyandot, Seneca and Sandusky), the 1967 Conservation Needs Inventories by the U.S. Conservation Service indicate that 70% of the land is cultivated, 9% is in permanent pasture, 9% is forested, 6% is in other rural uses and 6% is urban. In 1973, the total cash receipts from farming in these four counties amounted to 154.8 million dollars (Ohio Agriculture Research and Development Center, 1974).

The Sandusky River arises at the confluence of Paramour Creek and Allen Run near Crestline, Ohio. The river drops from an elevation of 1,093 ft at its source to 573 ft where it empties into Sandusky Bay. It is about 130.2 mi long and has an average fall of about 3.9 ft/mi (Ohio Department of Natural Resources, 1966). The average discharge during 48 years of records at the stream gage south of Fremont, Ohio is 946 ft^3/s or 10.27 in/yr (U.S. Department of Interior, 1974). The drainage area above that stream gage is 1,251 mi^2. The maximum observed discharge during the

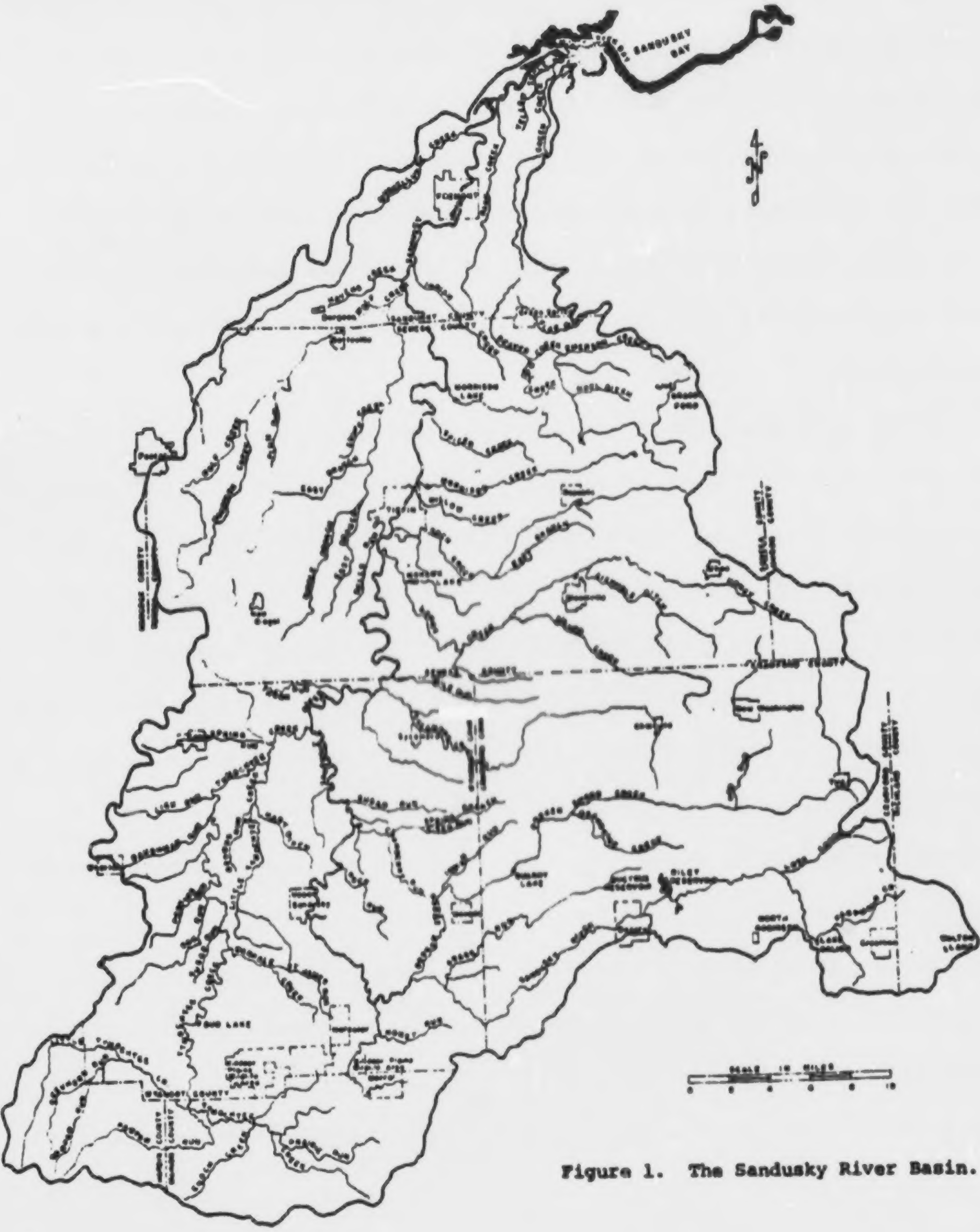
SANDUSKY BAY
SCALE IN MILES
0
2
4
6
8
10

Figure 1. The Sandusky River Basin.

period of record amounted to 28,000 ft^3/s and occurred February 10, 1959. The minimum discharge at the same station occurred during a period of severe freezing on February 29, 1974 and equalled 4.4 ft^3/s.

An important feature of the Sandusky River and its major tributaries is the virtually continuous corridor of woody vegetation which extends along the stream banks. This vegetation provides both visual relief to the intensively cultivated landscape and, for those on the river, an effective screen from the surrounding dominant land use. The vegetative corridor links many of the remaining woodlots within the basin and consequently may be very significant in helping to maintain the diversity of wildlife present in the basin.

Numerous public and private recreational parks and camps are situated along the mainstream and its tributaries. In January 1970, a 70 mile section of the Sandusky River from Upper Sandusky to Fremont was designated an Ohio State Scenic River. This designation will facilitate the development of the recreational potential offered by the river and its adjacent land areas. As of 1975, five new areas have been obtained by the state to provide additional public recreational facilities on the river. The recreational features of the Sandusky River are described in detail in two publications, the *Sandusky Scenic River Study* (Ohio Department of Natural Resources, 1969) and an illustrated book entitled *Down the Sandusky* (Grob, 1971).

The Sandusky River provides the public water supply for the four largest cities in the basin. In both Bucyrus and Upper Sandusky, river water is pumped into storage reservoirs prior to treatment. For both Tiffin and Fremont, water is withdrawn directly from the river for treatment and subsequent distribution. In the vegetable crop areas between Tiffin and Fremont, use of the river for irrigation is increasing. There is also some direct industrial use of surface waters in the basin.

WATER QUALITY

Two sections of the Sandusky River have serious and chronic oxygen deficiencies. During summer low-flow conditions, the stream below Bucyrus shows the typical dissolved-oxygen sag which is characteristic of sewage pollution. Bucyrus does have secondary sewage treatment and chlorination. However, a combined storm and sanitary sewer system, as well as inflow and infiltration problems, result in flows which often exceed the capacity of the sewage treatment plant. This, coupled with the fact that often more than 50% of the stream flow immediately below Bucyrus is treatment-plant effluent, creates serious pollution problems in this area.

The oxygen monitor below Fremont often shows anaerobic conditions in late summer (U.S. Department of Interior, 1974). Water-quality management in this area is complicated by the estuary-like conditions in the river. From Fremont to Sandusky Bay the river is essentially at lake level. Fremont does have a secondary sewage treatment plant with sufficient capacity to handle normal domestic waste loads. In late summer, additions of organic wastes from food-processing plants result in total organic loads which apparently exceed plant capacity. The resulting organic loading into the river produces the oxygen problems.

Apart from the two river stretches described above, evidence of organic pollution from inadequate municipal sewage treatment is generally lacking in the mainstream. The river is nevertheless plagued with a variety of what may be called "second generation" pollution problems. Often these problems are related to land use within the basin.

The most visible of these problems is the high sediment concentration and the high turbidity which generally characterize the river. These sediments not only detract from the aesthetic quality of the river, but they, and their associated inorganic nutrients, may contribute significantly to water-quality problems in Lake Erie. Sheet erosion is apparently the dominant source of this sediment.

The concentration of fecal coliform bacteria exceeds recommendations for both primary and secondary contact recreation along virtually the entire length of the river. Rural septic tanks, inadequate sewage-collection systems in towns, combined sewer overflows, package treatment plants, and animal wastes can all contribute to this problem.

Algal blooms occasionally reach nuisance levels during periods of low stream flows. Most of the oxygen violations along the stream are associated with diurnal oxygen fluctuations rather than oxygen-sag curves. The high phytoplankton concentrations, as well as high sediment concentrations, give rise to periodic taste and odor problems in the drinking water. Occasionally, windrows of floating algae develop, detracting greatly from the aesthetic values of the river.

Oil and chemical spills along the river and its tributaries are fairly common and occasionally result in fish kills. Such spills within municipal sewage-collection systems result in the by-passing of both the spilled material and raw sewage directly into the river at the sewage treatment plant. The oils or chemicals have to be bypassed to prevent poisoning of the biological components of sewage treatment processes.

The geological nature of the basin results in high levels of dissolved solids and hardness, particularly during periods of low stream flow. Often the dissolved solids attain such a high level that industries must store large volumes of water with high dissolved solids, since the river wate already exceeds drinking-water standards and has no capacity to dilute additional wastes.

WATER MANAGEMENT OPTIONS

In the two instances where chronic dissolved-oxygen problems occur, the remedies are fairly apparent. Bucyrus needs an expansion of its sewage-treatment plant and/or major improvements in its sewage-collection system. In the case of Fremont, additional industrial pretreatment would probably be the most efficient way to reduce seasonal organic loading into the river. These improvements are being initiated through the efforts of the Ohio Environmental Protection Agency.

For the "second generation" types of water-quality problems, the remedies are either not so apparent or else extremely expensive. It remains to be seen whether enforcement of Ohio's Agricultural Pollution Abatement Laws will significantly reduce sediment and nutrient yields from the Sandusky River Basin into Lake Erie. These laws, with respect to erosion, are designed to protect the suitability of the land for continuous food production (Co-operative Extension Service, 1975). Tolerable soil losses with respect to the land may give rise to intolerable or at least undesirable sediment and nutrient yields to Lake Erie.

Given the dominance of rural non-point sources in the overall nutrient loading from the Sandusky Basin into Lake Erie (Baker and Kramer, 1973), there is only limited potential for reducing nutrient yields through the addition of advanced waste treatment at municipal sewage treatment plants. Whether advanced waste treatment will significantly reduce the occurrence of nuisance algal growth in the Sandusky River is open for question. In river systems, low stream flows may well be more important than nutrient concentrations in providing conditions for phytoplankton development. Consequently, flow augmentation from upground reservoirs in the basin could help control excessive algal growths.

Even though all of the municipalities in the basin have chlorination, the fecal-coliform bacterial counts are high throughout the river system. If rural septic tanks are a major source of these bacteria, laws controlling the installation of new septic tanks will have little effect on existing conditions. The extension of sewer lines into rural areas and the separation of combined storm and sanitary sewers are very expensive. Achieving bacterial levels satisfactory for primary-contact recreation throughout the basin will be very difficult.

Since many of the water-quality problems in the Sandusky Basin are related to land use, water-quality improvements could accompany improvements in land use within the basin. Improved land use requires both improved land-use planning and the implementation of the plans. Since water quality is only one of the many factors that must be considered in land-use planning, it remains to be seen whether improvements in land-use will significantly affect water quality.

Figure 2 summarizes some of the management options mentioned above, as well as some of the desirable improvements in water quality. The

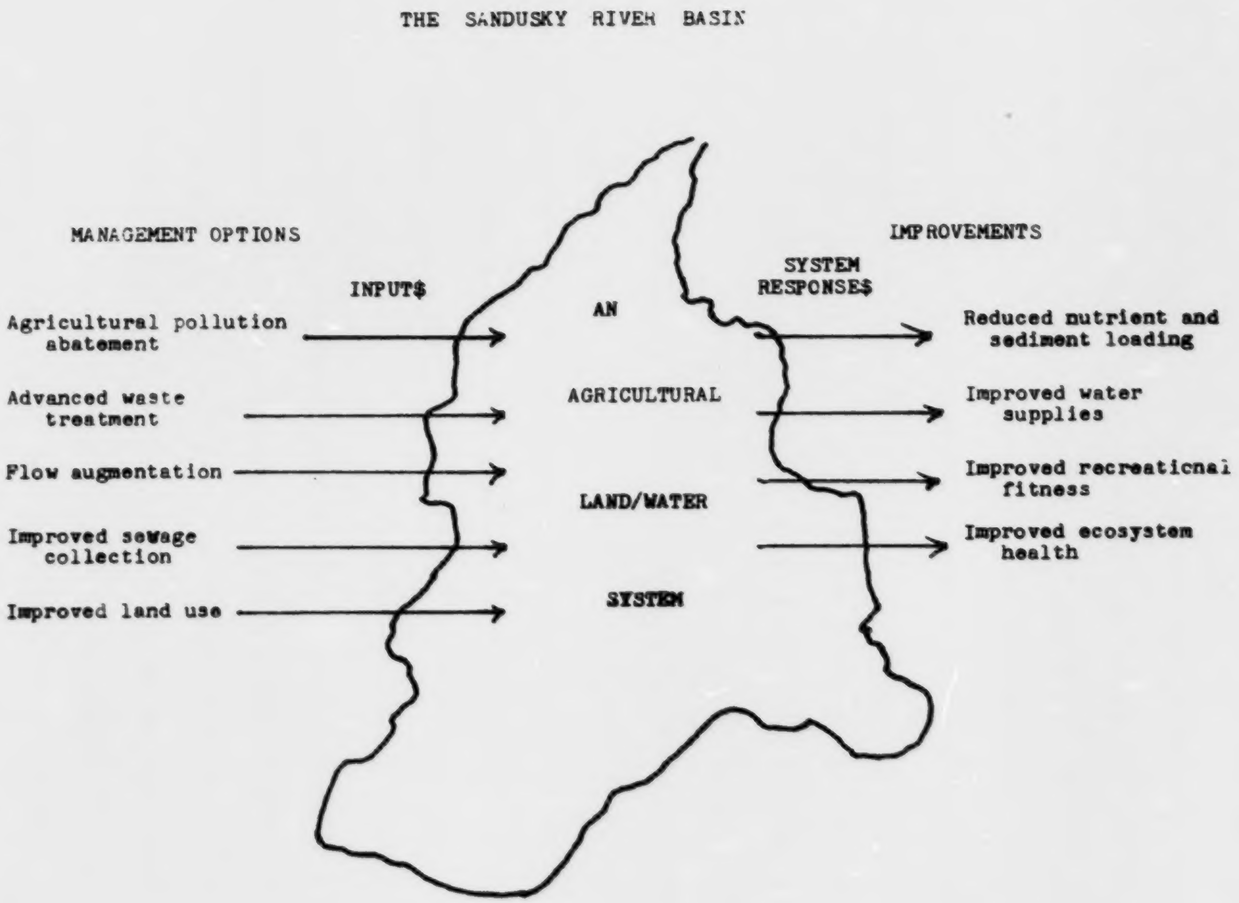
THE SANDUSKY RIVER BASIN
MANAGEMENT OPTIONS
INPUT$
Agricultural pollution abatement
Advanced waste treatment
Flow augmentation
Improved sewage collection
Improved land use
AN
AGRICULTURAL
LAND/WATER
SYSTEM
SYSTEM RESPONSE$
IMPROVEMENTS
Reduced nutrient and sediment loading
Improved water supplies
Improved recreational fitness
Improved ecosystem health

Figure 2. A summary of the water management options available and water quality improvements needed within the Sandusky River Basin.

diagram serves to remind us that the Sandusky Basin is a 1,400 square mile, agricultural land - water system. To the extent that existing land use in the basin is responsible for less than desirable water quality, significant improvements in water quality may require significant changes in land use in the basin. At present the causal linkages between inputs and system responses are not always clear, especially with respect to "second generation" water-quality problems. Consequently, the effectiveness of selective land-use changes or other specific management options for achieving specific improvements in water quality is difficult to predict, let alone analyze in terms of costs and benefits.

WATER QUALITY RESEARCH IN THE SANDUSKY BASIN

A considerable amount of water quality research and monitoring has taken place within the Sandusky River Basin. This work includes the monitoring efforts sponsored by various governmental agencies, such as the U.S. Geological Survey, the Ohio Environmental Protection Agency and the Ohio Department of Natural Resources. These governmental monitoring programs are common to many river basins.

The Sandusky Basin and Bay Areas have also been the locale of many diverse and detailed studies performed by various agencies and institutions. Many of these studies, both past and present, were carried out independently of one another. Other studies, by their very nature, required cooperative efforts. Hence the river transport studies at Heidelberg College have relied heavily on the cooperation of the U.S. Geological Survey, the Ohio Environmental Protection Agency and the Ohio Department of Natural Resources. More recently, the water quality studies of Bowling Green State University, the Ohio Environmental Protection Agency and Heidelberg College have been coordinated to a considerable degree.

There has been no funding to support a comprehensive river basin study in the Sandusky Basin. The Sandusky Basin Symposium provided a forum for pulling together existing studies of relevance to some contemporary environmental considerations relating to water quality. Our contemporary analysis of environmental problems in the basin also has benefitted greatly by the historical perspectives which several of the contributors were able to provide.

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ABSTRACT

THE GEOLOGIC SETTING OF THE SANDUSKY RIVER BASIN

JANE L. FORSYTH

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The Sandusky River Basin occupies glaciated plains composed of late Wisconsin ground moraine crossed by three major end moraines (N-S: Defiance, Fort Wayne, Wabash) and locally capped by lake sediments, especially north of Tiffin (where sand ridges of ice-damned lakes Maumee, Whittlesey, and Warren occur, with lake-bottom silts north of the Warren beach) and also in two small areas in the south (northwest and southeast of the Wabash Moraine). The underlying bedrock is fairly shallow (about 40 feet deep) and is mostly Silurian-Devonian carbonates, with Devonian shale and Mississippian sandstone farther southeast, all occuring as the eroded edges of gently dipping strata on the east flank of the Cincinnati Arch. These carbonates provided lime to the overlying glacial drift, so that both the ground water and the surface water (fed by springs of un-sun-warmed ground water) are alkaline. Cutting northward across this landscape are the Sandusky River and its tributaries, with gentle gradients (averaging about four feet per mile) and gravelly (south) or muddy (north) bottoms, except where rock is exposed.

The geologic history of this area began as the glacier retreated out of Ohio about 14,000 years ago, after which, for another 1,500 years ice blocked the eastward flow of Lake Erie, forming a series of lakes which here extended as far south as Tiffin. When glacial retreat finally permitted initiation of eastward drainage, the Niagra outlet was so low, due to the weight of the ice that had buried it, that most of Lake Erie drained away suddenly in a great flood. The Sandusky River extended itself across the newly exposed lake bottom, joining one or more other extended rivers from the west (Maumee, Detroit), and flowed eastward into the tiny eastern remnants of the earlier lake. As the Niagra outlet subsequently raised isostatically, first fast (30 feet/century) then slower (now only about 1/2 inch/century), the lake level slowly rose, flooding first the eastern lake bottom, then the western, finally creating islands out of the rocky hills north of Sandusky. The extended Sandusky River became increasingly shorter, with lake water flooding its lower reaches, as it does today as far south as Fremont. Recovery of the lake level was interrupted by the warmer, dryer Xerothermic Interval, dating from about 10,000 to 4,000 years ago and identified by a lack of mesic species (beech) in the pollen records of postglacial climactic change.

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THE GEOLOGIC SETTING OF THE SANDUSKY RIVER BASIN

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INTRODUCTION

Any field biologic study requires knowledge not only of the organisms themselves but of the abiotic environment in which they live. One part of the abiotic environment is the local climate, but all other parts of the environment are related to the geology of the site. Included in the site's geology are the geologic *materials*, or substrates, of the area; the geologic *processes*, or natural disturbance-producing processes, and their results; and the geologic *history*, or sequence of events which took place in the past but which may influence present organisms. Clearly, an adequate understanding of the geologic setting is essential for any problem in field biology.

In the Sandusky River Basin, the geologic materials are of two main types, the solid *bedrock* and the overlying *mantle* of unconsolidated materials, which are mainly glacial in origin. Although the bedrock is mostly buried, it plays an important role in the geologic setting, first because it is exposed in some places, particularily along the valleys of the Sandusky River and some of its tributaries, and thus represents the substrate in these places, and secondly because it has influenced the nature of the unconsolidated deposits that overlie it. These overlying deposits, or mantle, are composed mostly of glacial till, locally covered by relatively thin glacial-lake deposits, and, along all the stream valleys, by alluvial deposits, and all contain particles of the underlying bedrock. In addition, much of the water in the Sandusky River system, though it was originally surface water, has seeped through the ground before emerging as springs, so that the water's natural chemical characteristics are largely a product of the effects of the bedrock and of the overlying bedrock-influenced mantle.

The geologic processes now active in the Sandusky River Basin are mainly the flooding and erosion of rivers, the flow of cool (during the summer growing season) alkaline spring water into the rivers, and the flooding and erosion of Lake Erie, especially in recent years. Processes active on the upland areas, away from streams, springs, and Lake Erie, such as weathering, raindrop erosion, and slope wash, are much slower and contribute little to the geologic setting of the Sandusky River Basin area. Other processes are those attributable to man, the changing of surface drainage and the contribution of pollutants to the waters of the Sandusky drainage.

The geologic history really begins with the story revealed by the oldest bedrock, but that earlier history provides little meaningful background for understanding the distribution of modern organisms, so the geologic history presented here and considered critical for the biological studies of the modern Sandusky River Basin begins with the retreat of the last (Wisconsin) glacier from northern Ohio. This includes the story of the glacially dammed lakes in the Lake Erie basin, the great flood and resultant extension of the Sandusky River of that time across the old lake plain, and the postglacial vegetational history revealed in the pollen record.

Each of the geologic subjects mentioned above is discussed below in detail, first materials and then history. Geologic processes are not dealt with separately, but are combined with materials. It should be pointed out that this presentation is in the form of an introductory overview and thus does not follow the normal style of scientific writing that characterizes the rest of the papers in this proceedings.

Bedrock

All of Ohio has bedrock that is sedimentary and of Paleozoic age. In addition, it is almost flat-lying. The main exception is a very gentle arching of the rocks throughout the state, the crest of the arch extending from a position just west of the Sandusky River Basin area south-southwest through Cincinnati, hence the name of this structure, the Cincinnati Arch (locally known as the Findlay Arch in northwest Ohio). Erosion of the rock layers composing this arch has resulted in the removal of most of the younger layers on its crest in western Ohio, where the arched rocks stood highest, and the removal of less and less of the overlying layers to the east, down the eastern flank of the feature, as shown in Figure 1. (The western flank lies in Indiana.)

Most maps showing the bedrock geology of Ohio use mapping units based on the geologic age of the rock, rather than on its composition (Bownocker, 1920). However, Ohio's bedrock is fairly simple, and most strata of a single age in the state are composed of the same basic rock type. These characteristic compositions of bedrock of a single age in Ohio are listed below (note that, following normal geological procedure, the older rocks are listed at the bottom). Names used for ages of the rock here are names of periods, the main subdivisions of eras, in this case the Paleozoic Era.

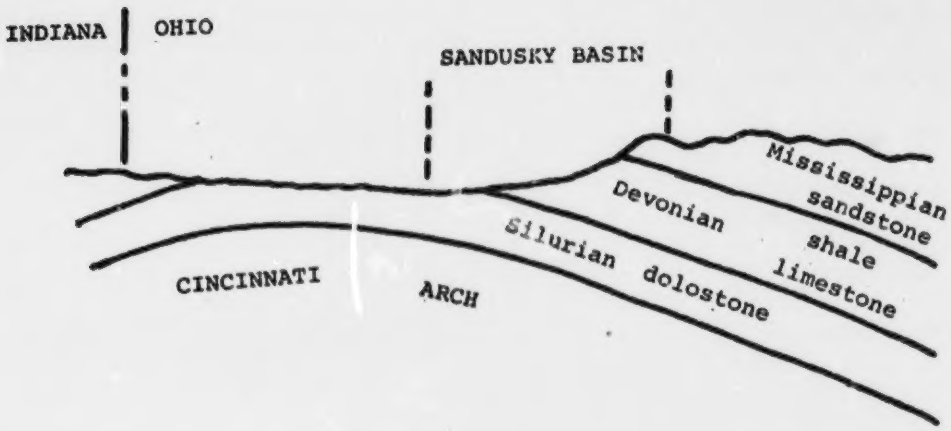

INDIANA
OHIO
SANDUSKY BASIN
Mississippian sandstone
Devonian
shale
limestone
Silurian dolostone
CINCINNATI
ARCH

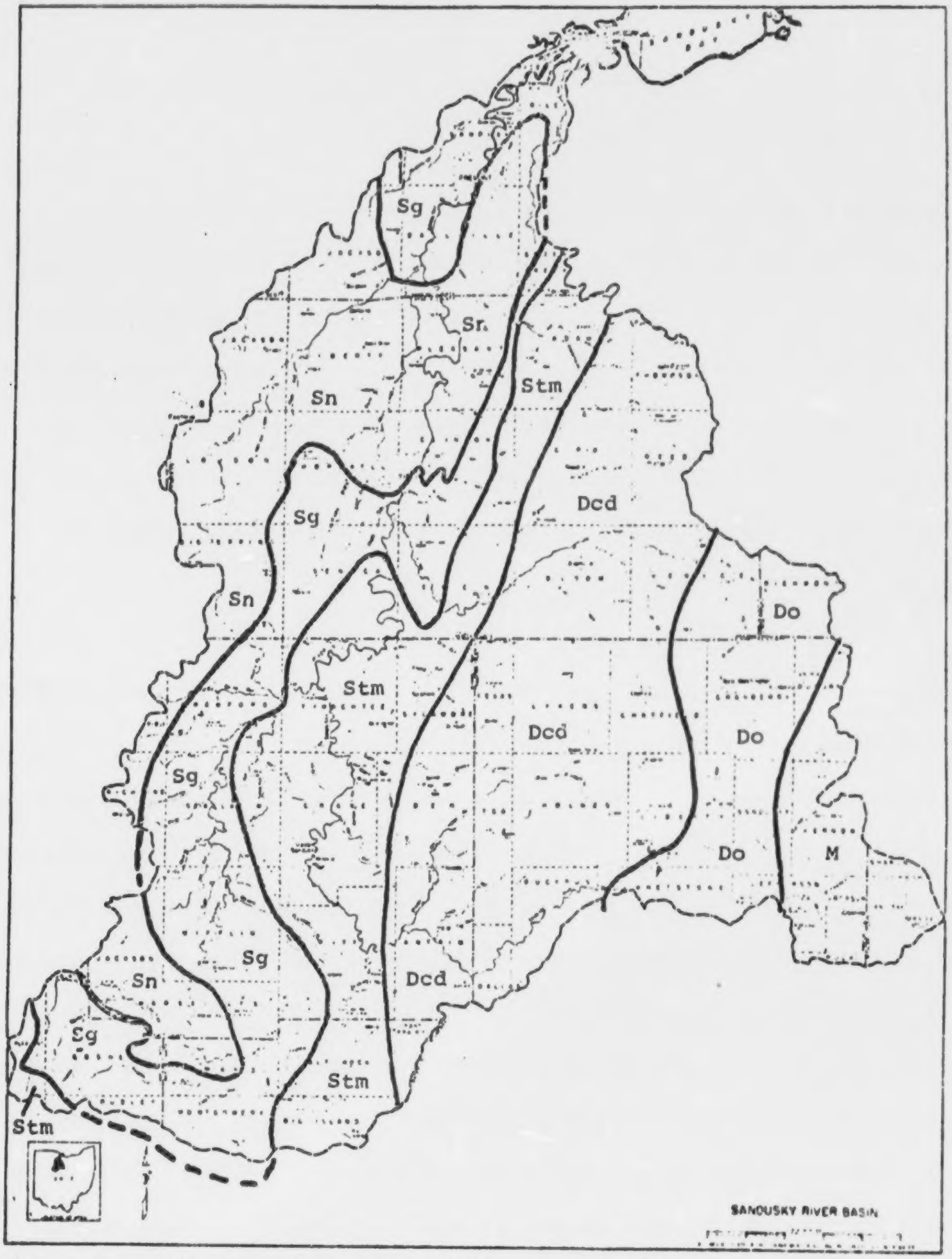
Figure 1. Generalized cross-section of Ohio's bedrock. Cross-section diagrammatically shows how erosion of the Cincinnati Arch has produced the arrangement of older (Silurian and Devonian) bedrock in the west and younger (Mississippi) bedrock in the east in Ohio. The Sandusky River Basin area lies mainly on the outcrop areas of Silurian dolostone and Devonian limestone, but Devonian shale and Mississippian sandstone underlie the easternmost part.

Rock types characteristic of each geologic period in Ohio

Paleozoic periods	Dominant rock types
Permian	Coal measures (sandstone and shale with local thin layers of coal, clay, and limestone)
Pennsylvanian	
Mississippian	sandstone and shale (soft, brown)
Devonian, Upper	shale (hard, thin, black)
Middle	limestone
Silurian	dolostone (magnesium-bearing limestone)
Ordovician	alternating thin layers of limestone and thick layers of limy shale, all very fossiliferous
Cambrian	not exposed at the surface (mainly limestone)

The Sandusky River Basin lies just east of the crest of the Cincinnati (or Findlay) Arch, where the eroded rock layers are mainly of Silurian and Devonian age (figures 1 and 2). The Silurian rocks, which include the Lockport, Greenfield, Tymochtee, and Salina Formations (composing most of the "Monroe" - Bownocker, 1920), are all *dolostones*. Dolostone is a rock formed dominantly of the mineral dolomite (composition $(Ca.Mg)CO_3$), in contrast to limestone, which is made up mostly of the mineral calcite (composition $CaCO_3$), and characteristically has fewer fossils than most of Ohio's limestones. It also generally contains many small irregularly shaped openings produced by the recrystallization that took place shortly after the limy ooze, which was to make the rock, had accumulated on the ancient sea floor here and before it had been changed into solid rock.

To the east of the Silurian rocks in the Basin area are the Devonian and Mississippian strata (figure 2). Most of the Devonian is composed of


Sg
Sr
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Stm
SANDUSKY RIVER BASIN

Figure 2. Bedrock geologic map of the Sandusky River Basin area. Bedrock units are identified by the following symbols.

M - Mississippian Berea Sandstone (and other Mississippian units)
Do - Devonian Ohio Shale
Dcd - Devonian Columbus and Delaware Limestones
Stm - Silurian Tymochtee and "Monroe" Dolostones
Sg - Silurian Greenfield Dolostone
Sn - Silurian Niagaran-aged Lockport Dolostone

All these rock units are dipping very gently to the east, as a result of their location on the east limb of the Cincinnati Arch (figure 1).

limestone that is quite fossiliferous, the same Columbus and Delaware Limestones that are extensively quarried farther south near Columbus, Delaware, and Marion. Farther east, in the upper reaches of the Sandusky River Basin, are two formations: the Devonian shale, a hard, black, thin-layered shale (mistakenly called "slate" by some), locally containing large round concretions, called the Ohio Shale, and a basal Mississippian sandstone called the Berea Sandstone (the rock that is quarried locally southwest of Cleveland near North Olmsted).

Concretions occur in a number of Ohio rock formations, but only in the Ohio Shale are they so large or so famous. (These concretions decorate many a central-Ohio dooryard.) Concretions are believed to form early in the history of such a sediment, before the compaction that accompanied the change from sediment to sedimentary rock has taken place. Water containing soluble materials, such as iron carbonate, in solution apparently seeps down through the pores of the unconsolidated mud, the carbonates precipitating out in a spot dictated by the local chemistry. This precipitate fills the pore spaces in that part of the sediment, the filling expanding outward from a center in all directions, forming a spherical shape. When the sediment subsequently becomes compacted into shale rock, this spherical area contains too much precipitated mineral matter to permit it to become compacted, so the shale layers bend around the solid mass. Later, when weathering and erosion take place, this mass does not break down as readily as does the surrounding shale, so the spherical mass comes out as a solid ball-shaped concretion (Hoover, 1960; contrary to origin reported by Barth, 1975).

As a result of the erosion of all these different rock layers on the crest and eastern flank of the Cincinnati (or Findlay) Arch, most bedrock present in western Ohio is carbonate -- limestone or dolostone -- and most bedrock found in eastern Ohio is sandstone. The Ohio Shale, which occurs stratigraphically between the Silurian-Devonian carbonates of western Ohio and the younger sandstones and shales of eastern Ohio, forms a narrow north-south belt along the line separating these other two rock provinces, a belt that passes through the east-central part of the Sandusky River Basin area. Limestone and sandstone are very different in their resistance to erosion; limestone and dolostone are fairly nonresistant, so that land underlain by these rock types tends to appear as flat plains, whereas sandstone is quite resistant, forming hills. Shale is also relatively nonresistant, but, wherever it is overlain by the younger resistant sandstone, the shale characteristically forms the slopes of the sandstone-capped hills (such as along Rocky Fork in Cleveland or in the hills near Chillicothe, including Mt. Logan, on the State seal). Thus, the landscape of Ohio is basically one of plains in the west and hills in the east. (This is why the glacier moved all the way south to the Ohio River in western Ohio, where it was unimpeded by hills, but advanced only a short distance south in eastern Ohio, only approximately to the latitude of Canton.)

In the Sandusky River Basin area, which lies on the eastern flank of the Cincinnati (or Findlay) Arch, most of the underlying bedrock is Silurian-Devonian carbonates, which together with the till mantling them, produce a relatively flat landscape, except where the Sandusky River and its tributaries have cut valleys into these plains. In the southeastern part of the Basin, however, where the underlying bedrock is shale and sandstone, a landscape that is higher and steeper has been produced.

It should be emphasized that, in the entire Sandusky River Basin area, practically all of this bedrock, despite its influence on the landscape, lies buried beneath a considerable thickness of mantle -- mostly glacial till, with some lake deposits and some river alluvium. The average thickness of this cover, and thus the depth to bedrock, is roughly 40 feet, but it is considerably thicker in some buried valleys and thins to zero where the bedrock crops out. Only in a very few places, where the river has eroded away the mantle or where man has dug a quarry, can the bedrock actually be seen. On the other hand, even where it is buried and invisible, the bedrock plays a very important role in the geologic setting of the Basin area.

First of all, fragments of the local bedrock, in all sizes from clay to boulders, are the main material composing the glacial till. Apparently the advancing glacier obtained most of the rocky debris that it carried by freezing onto and carrying away (i.e., "plucking") bits of the local rock. Thus, all the till in the area is very limy, even that lying on the shale and sandstone bedrock to the east, where the glacier carried bits of carbonate bedrock, plucked from subglacial exposures of weathered limestone and dolomite to the west, and incorporated them into the till that it deposited. In addition, limestone can be ground more finely much more readily than can sandstone, with the result that this till is not only more limy, but also more clayey, so that the presence of such till on the acid, infertile sandstone has had a profound effect on substrates there.

Secondly, any water moving through the ground and emerging at the surface as springs (or natural upwellings of ground water at the surface) is high in dissolved lime (is alkaline or "hard") because of the great amount of lime available by solution from either the carbonate bedrock, or the lime-rich glacial till, or both. Thus, all surface or near-surface waters in the Sandusky River Basin area are high in dissolved lime, except in the rare sites where there are local accumulations of acid organic materials at the surface (or where man has contributed such acidic organic materials to the water).

Such spring water is not only alkaline but also tends to be much cooler than the surface water during the summer growing season, and to have a uniform, continuous flow. Actually, the water is cooler in summer and warmer in winter, in comparison to surface water, because it has the temperature of the ground where it has been, ground which is so deep that the water is neither cooled by winter storms nor warmed by the sun during the summer. Thus , in the winter, spring water does not freeze, whereas, during the summer growing season, spring water is cooler than surface water and can support those special species of plants and animals for whom cooler microclimates are required. In addition, because the water moving through the ground must seep through the pores and around the grains of the material there, it moves extremely slowly, and thus flows more or less continuously both through the ground and out through the springs at the surface, even during drouths. Thus, during the critical growing season of most plants, springs in the Sandusky River Basin area, most of which occur within the river channel, provide cool, alkaline, continuously flowing water.

Mantle

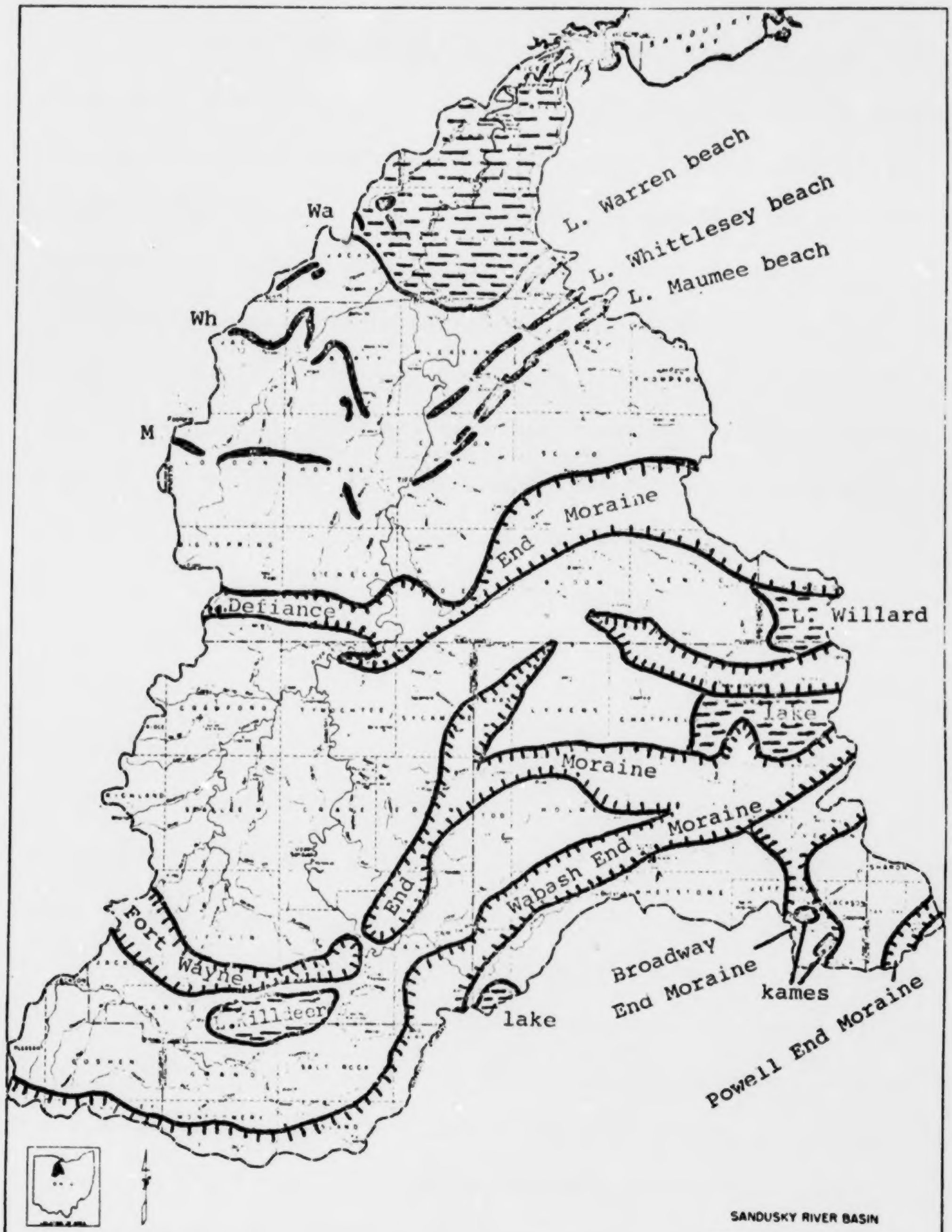
The term mantle (or *regolith*) refers to all the unconsolidated materials lying on the bedrock, regardless of origin. Glacial till forms the mantle throughout most of the Sandusky River Basin area, but lake deposits are present in the northernmost part, north of Tiffin, and also in four fairly small areas in the south (including Killdeer Plains), and alluvial deposits occur all along the river valleys. Almost everywhere where lake deposits are present, they are underlain at relatively shallow depths by till. Alluvial deposits also occur on till in most areas, but in a number of places, particularily along the Sandusky River itself, they lie directly on the bedrock. Indeed, most of the places where the local bedrock itself is exposed in this area also occur along the Sandusky River valley.

Glacial deposits

Most glacial deposits within the Sandusky River Basin area are composed of *till* (a heterogeneus unsorted mixture of much clay with smaller amounts of silt, sand, pebbles, and scattered boulders), material that was left when the glacial ice which originally transported it here melted away. The till forms two different deposits: *ground moraine* and *end moraine*. Wherever ice containing rock fragments melted, the rock fragments were simply "dumped", or let down, as the ice melted away, forming the till. Where this till is spread uniformly over the ground, producing a relatively flat landscape (as is found throughout much of western Ohio), the deposit is called ground moraine. In places, however, the rate of forward motion of the ice just equalled the rate of melting, so that the edge of the glacier remained in one position for some time. When this happened, the rock debris released by the melting glacier was piled up into a belt of hills along the edge, or end, of the glacier, forming a linear band of low hills composed of till called an end moraine (descriptive term for the genetic types: terminal moraine and recessional moraine) (Goldthwait, 1959).

Three major end moraines occur within the Sandusky River Basin area, together with small segments of three others (Leverett, 1902; Goldthwait, White, and Forsyth, 1961) (figure 3). Extending east-west across the middle of the Basin is the Defiance End Moraine, the northern-most end moraine in western Ohio (Goldthwait, White, and Forsyth, 1961). Like the other end moraines, the area covered by this moraine is characterized by a linear belt of low rolling or hummocky hills, with its highest elevations forming a crest extending more or less east-west near the southern boundary of the moraine. The land here is clearly higher and more irregular than is adjacent land, but no slopes are steep enough to produce any significant effects of aspect (e.g. of a south-facing slope), though the soils through much of the belt are somewhat better drained than are those to the north and south of the feature.

Cutting across the southern part of the Basin are the other two major moraines of the area, the Fort Wayne End Moraine, in southern Wyandot and northernmost Crawford Counties, and the Wabash End Moraine, in northern Marion and central Crawford Counties (figure 3). The appearance of these moraines is like that of the Defiance End Moraine, but the pattern is more complicated, especially in Crawford County, because of higher land there, on the underlying resistant sandstone bedrock. The Fort Wayne Moraine here becomes double, one section bending sharply north and locally becoming too low to be mapped across this somewhat higher sandstone-based landscape, the other section extending eastward across north-central Crawford County to join the Wabash Moraine in Liberty Township of Crawford County.


L. Warren beach
L. Whittlesey beach
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Wh
M
End Moraine
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L. Willard
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Fort Wayne
Killbeen
lake
Broadway
End Moraine
kames
Powell End Moraine
SANDUSKY RIVER BASIN

Figure 3. Glacial map of the Sandusky River Basin area. Glacial deposits shown are end moraines (enclosed by hashures and named), ground moraine (left white), lake beaches (marked by black bands and named), and lake-bottom silts and clays (identified by horizontal-dash pattern). Areas of alluvial deposits along the Sandusky River and its tributaries are too small to be shown on this map.

The three small segments of other end moraines present in the southeasternmost part of the Basin area represent small parts of what are major end moraines elsewhere in Ohio (Goldthwait, White, and Forsyth, 1961). Listed in order of age, the youngest first, these are the Wabash, the Broadway, and the Powell End Moraines (figure 3). All of these end moraines have a generally north-south orientation, because they occur along the eastern margin of a lobe of ice (the Scioto Lobe) that, to the west, extended farther south, but here, along the east edge of that lobe (and in the southeastern corner of the Sandusky Basin area), impinged on the edge of the higher land to the east, held up by the resistant sandstone bedrock.

Farther west, where the bedrock is limestone and dolostone, the buried bedrock surface is lower and flatter than in the east. However, two shallow bedrock ridges oriented north-south are also present there, one in western Crawford County, the other in southwestern Wyandot and northeastern Hardin County. These north-south bedrock ridges, even though they are buried beneath glacial till, create low ridges on the modern landscape, too, ridges which, in conjunction with the east-west-oriented end moraines, have resulted in a criss-cross pattern of topography with intervening shallow depressions. These depressions contained shallow lakes or marshes, following the retreat of the glacier, and a few still have marshes in them (e.g. Killdeer Plains)(Forsyth, 1973).

The melting ice produced great streams of meltwater, which locally eroded the till, washing and reworking the materials composing the till. The finer sized materials, the silt and clay, were washed by the meltwater on down the south-flowing streams into the Ohio River, and thence on down the Mississippi River to the Gulf of Mexico, where they contributed to the building of the great Mississippi delta. The coarser materials, the gravel and sand, were washed across the glacial surface and became deposited nearby, either in holes in the ice (crevasses) or beyond the ice in the valleys of streams carrying glacial meltwater away from the glacier (Goldthwait, 1959). Gravel fillings of holes in the ice now appear as hills of gravel (or, more commonly, gravel pits) and are called *kames*. Only two are mapped within the Sandusky River Basin area, both in the far southeast, in Jefferson Township of Crawford County, in the area of the Broadway Moraine. (Gravel pits southeast of Tiffin, suggested by some in the past to have been in kames, are actually located in till-covered sand-and-gravel deltas associated with the earliest of the ice-dammed lakes in the Lake Erie basin, and are discussed later, under "glacial-lake deposits").

Gravel that accumulated in river valleys beyond the ice is called *outwash*. No outwash occurs at the surface within the Sandusky River Basin area, as no streams within this area flowed southward, away from the glacier, during the time of glacial melting, but some outwash that is present farther south was deposited by meltwaters pouring from the Broadway and Powell End Moraines, sections of which occur in this basin (Kempton and Goldthwait, 1958; Goldthwait, White, and Forsyth, 1961). In addition, gravel layers buried several tens of feet beneath the surface till, especially in the southern part of the basin, from which ground water is now obtained by wells (Stein, 1962a, 1962b), are probably older outwash deposits.

Glacial-Lake Deposits

Lake deposits occur in both the northern and the southern parts of the Sandusky River Basin area. Those in the north are related to earlier, higher stages of Lake Erie and include sand beaches, sand bars, and silt-and-clay bottom sediments. To the south, there are four areas where a marsh or shallow lake once existed and locally still persists, the extent of the feature being represented by organic-rich silty clay lacustrine (lake) deposits.

The earlier, higher stages of Lake Erie in the north were produced by a dam of glacial ice, the edge of the retreating glacier, which lay in the eastern end of the Lake Erie basin, burying the present Niagara outlet with ice and blocking the eastward drainage of the lake. This caused the lake waters to back up, flooding higher and higher, until the level of the next lowest, ice-clear outlet was reached. This outlet was located first at Fort Wayne, Indiana, later through the Grand River of Michigan, both of these routes leading eventually into the Mississippi drainage, and ultimately, when the ice had retreated far enough to the north, eastward into the Ontario basin. As the ice alternately retreated and readvanced during its overall recession from Ohio, a number of different individual outlets were used, the elevation of each outlet determining the elevations of both the lake at that time (the level of any lake is determined by the elevation of its outlet) and its associated beaches and sand bars. (This brief survey of the lake history of northern Ohio is greatly expanded later, in the section on geologic history.)

Three major beaches are recognized, those of Lake Maumee III at 780 feet, of Lake Whittlesey at 735 feet, and of Lake Warren at (and below) 690 feet, with other intermediate levels that are less well developed, either because they were flooded by a subsequent rise in lake level created by a readvance of the ice, or because they lasted such a short time (Leverett, 1902; Leverett and Taylor, 1915; Hough, 1958, 1963, 1966; Dreimanis, 1969; Calkin, 1970; Forsyth, 1959, 1971a, 1973; Dorr and Eschman, 1970). Lake-bottom silts and clays are relatively thin, on top of the underlying glacial till, and occur only north of the Lake Warren beach, though they are fairly widespread there. Thus, the main lake deposits recognized in the northern part of the Sandusky River Basin area are the three strongest beaches and the lake-bottom silts and clays north of the Warren beach, all of which are of restricted extent within the Sandusky River Basin area because the Basin is so narrow in its northern part.

Modern lake deposits are forming locally along Lake Erie today, though these are mainly outside the Sandusky River Basin area. These are a result of modern lake erosion and deposition, processes whose effects have increased greatly in recent years as a result of the especially high lake levels of 1969-1973. The lake has been high because of a combination of excessive precipitation (especially in the upper Great Lakes drainage basin) and reduced evaporation (throughout all the lakes) in the years preceding those of the high levels. This is the result of a climatic pattern that is roughly cyclical, with highs and lows in the level of Lake Erie generally being repeated, very roughly, about every 21 years. Though the pattern of the cycle is extremely irregular, the existence of a very rough cycle is clearly demonstrated by data collected and published by the Lake Survey Center in Detroit (1972).

Independent and separate from this recent pattern of climatically controlled high and low levels of Lake Erie is a much earlier, postglacial isostatic rise in lake level,created by the slow uplifting of Canada after the melting of the heavy glacier there, which gently tilted Lake Erie southward and caused permanent flooding, thousands of years ago, of the lower ends of all tributaries of Lake Erie from the south (see section on geologic history). Sandusky Bay is the flooded lower valley of the Sandusky River, flooding which actually extends all the way up the river to below Fremont. Thus, when lake levels rose in 1969-1973 (as a result of the increased rainfall, *not* the postglacial isostatic effect), water levels along the river there rose, too, increasing the extent of lake-generated flooding and erosion problems, and resultant damage, in the Sandusky Basin area.

Erosion caused by the high lake levels, which was extremely severe in many places elsewhere along the shore of Lake Erie, was most extensive within the Sandusky River Basin area along the south shore of Sandusky Bay. Here, many tens of feet of easily eroded ancient lake sediments were washed away during each individual high-water storm, creating problems both from excessive erosion along the shore and from great increases in sediment offshore, both suspended in the water and accumulated on the bottom of the bay.

Lake deposits found in the southern part of the Sandusky River Basin area occur in the depressions described earlier, occurring in the criss-cross pattern produced by the generally east-west-oriented end moraines and the more or less north-south-oriented belts of higher land lying over shallow bedrock ridges (Forsyth, 1973) (figure 3). Most of these "lakes" were probably very shallow, not more than two or three feet deep at the most, and some may never have been more than just marshes; many probably dried up almost completely during late-summer drouths. The deposits themselves are generally organic-rich silty clay materials. Some of these depressions still contain marshes. Most famous of these is Killdeer Plains (figure 3), though the present marsh at this site is considerably smaller than it once was. A similar marsh occurs southeast of Killdeer Plains on the other (southeast) side of the Wabash End Moraine, though only a small part of the original extent of this marsh area lies within the boundaries of the Sandusky River Basin area (figure 3). A third, larger lake was present near Willard, in the eastern part of the Basin (mostly in southern Huron County), a lake that extended well east of the Basin boundaries, with another, even larger lake area just south of Lake Willard. No real lakes presently occur in any of these lake basins, and many are now cultivated. Other lakes or marshes were present in other depressions in this criss-cross pattern, but they lie outside of and to the southwest of the Sandusky River Basin area (Goldthwait, White, and Forsyth, 1961; Forsyth, 1973).

Alluvial Deposits

Alluvial (river) deposits are present along all the streams in the Sandusky Basin. Despite the large number of streams in the Basin, and the significance of the streams to the research reported on in the following papers, the extent of alluvial deposits in the Basin, in comparison with those of the glacial-till uplands, is very small. These deposits are basically a result of the erosion of the river banks and the settling out (deposition) of the resulting materials, both being typical river processes.

Streams erode very little except during times of flood. Under normal flow conditions, streams have only enough energy to flow and carry a little fine-grained sediment (which makes the stream look muddy), but not enough energy to do any erosion, especially with gradients as gentle as those found in the Sandusky drainage. Only during the very few hours of high flooding does major erosion take place, a period of time normally representing far less than one percent of the year (and not occurring at all during some years). However, with a very high flood, the amount of damage from both flooding and erosion can be very great, even in that brief interval of time. Not only do floodwaters submerge banks and extend back over normally terrestrial sites for considerable distances and for fairly long periods of time, but steep banks become undermined and collapse. Sediment derived from the erosion and undermining of these banks, as well as from erosion of the channel floor, greatly increases the stream's turbidity and then settles out on the channel bottom as the flood subsides, creating new but transitory alluvial deposits. Of all the natural sources of disturbance in Sandusky ecosystems today, those produced by river floods are probably the most common.

Alluvial deposits may be muddy, sandy, or gravelly, depending on the nature of the shore materials eroded and the energy of the stream that is available to move and sort these materials; coarse materials are dropped first, and finer materials settle out later, where stream energy has become less, thus causing *sorting* of the sediments deposited. When banks of clayey till are eroded, the small amount of coarse material -- sand and pebbles -- released from the till by the erosion and sorting action of the river water tends to accumulate close to the place from which it was eroded, commonly forming riffles. The finer material -- the clay and the silt -- does not settle out of the water so readily and is carried downstream suspended in the water, making it appear muddy, and accumulates in places where the water moves more slowly, commonly in pools, forming muddy bottoms there. Indeed, much of the finest material stays in suspension, keeping the water turbid and muddy, and does not settle out until the water reaches Lake Erie (e.g., Sandusky Bay).

Floodplains occur along all the main streams in the Basin, including the Sandusky River, and appear as low, flat land along these streams. These flat lands have been created by a combination of lateral erosion and sedimentation by the stream; because they are low, they are the areas regularly covered by water during high, overbank floods. The position of the river channel on the floodplain changes with time, as the current undermines banks, deposits sediment along channel margins, and sometimes cuts across new land during floods, creating new and different channel locations. Thus the sediment found on a floodplain is a combination of past river-channel deposits plus overbank-flood deposits. Organisms living on floodplains must be able to adjust to this difficult habitat -- to floods, siltation, undermining, and locally unstable substrates.

The intensity of river erosion, at any one place, and also the rate of flow are partly a result of the river's gradient, or rate of fall. Compared to most other rivers in Ohio, the Sandusky River and its tributaries have extremely gentle gradients. Indeed, the Ohio Department of Natural Resources will not include the Sandusky (or any other northwest-Ohio rivers) in their state-wide averages of gradient-dependent data for Ohio streams, because of the very gentle gradients here (Cross and Webber, 1959); the gradients are so slight that they would distort the overall state averages.

In general, the gradient of the Sandusky River is about four feet per mile. However, the gradient varies along the length of the stream and, indeed, is zero north of Fremont, where the river becomes just a long narrow bay of Lake Erie. Specific local values for the gradient of the Sandusky River and its two main tributaries, determined from 7½-minute topographic maps, follow.

Stream Gradients in the Sandusky River Basin Area

Location	River	Gradient in feet/mile
Sandusky County, north of Fremont	Sandusky River	0
" , south of Fremont	"	7
" , south by county line	"	5
Seneca County, north, near Old Fort	"	½
" center, north of Tiffin	"	15
" center, south of Tiffin	"	3
Wyandot County, north	"	4
" downstream	Tymochtee Creek	5
" center, south of Upper Sandusky	Sandusky River	3
" southeast, near county line	"	4
Crawford County, southwest	"	4
" downstream	Broken Sword Creek	4
" center, east of Bucyrus	Sandusky River	10
Richland County, west	"	4

GEOLOGIC HISTORY

The geologic materials found in the Sandusky River Basin area record a sequence of events that, taken in conjunction with similar data from adjacent regions in Ohio, reveals the geologic history of the area. The story told by the carbonate bedrock - an ancient clear, shallow ocean that was present here about 400 million years ago - reaches too far back to be of significance to the present biological studies of the Sandusky Basin, so this part of the area's geologic history is not included (information on this early phase of the geologic history can be obtained from Forsyth, 1968, or La Rocque and Marple, 1955). There was no Sandusky River in those days (the Paleozoic Era), nor during the long subsequent interval (through the Mesozoic and Cenozoic Eras) during which extensive erosion of the land took place.

Erosion in those days was by the Teays River in the south (Stout, Ver Steeg, and Lamb, 1943) and the Erigans River in what is now the Lake Erie basin in the north (Spencer, 1894), together with their tributaries, rivers which persisted for close to 200 million years and were only destroyed by the initial advance of the Pleistocene glaciers. One of the tributaries of the Erigans River, the Tiffin River (see Map 4 in Stout, Ver Steeg, and Lamb, 1943), flowed northward near the present valley of the Sandusky River, but its valley was not exactly the same as that of the Sandusky, and that river was destroyed when the Pleistocene glaciers first advanced southward over this area (Stout, Ver Steeg, and Lamb, 1943).

Rivers were formed and eroded the land during each of the interglacial intervals of Pleistocene time also, but almost nothing is known of their nature or distribution or effects. It was not until the retreat of the last (Wisconsin) glacier from Ohio that the critical geologic history of the Sandusky River Basin area began. With the retreat of the glacier from the Basin area, and the draining of the associated ice-dammed lakes, new land was opened up, in part of which an entirely new stream system began to flow - the initial Sandusky River -- and on which colonization of plants and animals could begin.

The geologic history of the Sandusky River Basin area, during the time following that of the Pleistocene glaciers, is presented in the following pages. It is divided into: glacial history, the history of the several ancient lakes (under several headings), the evolution of the Sandusky River itself (also under several different headings), and a very brief survey of postglacial vegetational and vertebrate life.

Glacial History

The Wisconsin glacier had come into Ohio about 25,000 years ago, had advanced southward across the state all the way to Chillicothe and Cincinnati by about 18-19,000 years ago (Goldthwait, 1958; Forsyth, 1961), and then was melting back when this history begins. That retreat must have been fast, for it lasted only about 4,000 years, and encompassed the formation of about 12 end moraines (Goldthwait, White, and Forsyth, 1961) and three major readvances (Goldthwait, 1959; Forsyth, 1965). (Note that a "retreating" glacier does not move back northward, but simply continues to advance southward at a rate less than that at which it is being melted away, so that it is really the glacial *margin* that is retreating.)

The first readvance took place in the southern part of the state. After retreating perhaps as far north as central Ohio, the ice edge readvanced back to the position of the Reesville End Moraine in Clinton County, overriding tundra-like vegetation (according to J. G. Ogden, III, in Moos, 1970) about 17,000 years ago (Moos, 1970). Then, after again retreating northward for some distance, perhaps as far north as the Lake Erie basin (creating an ice-dammed lake in which some lake clay must have accumulated - Forsyth, 1965), the glacier readvanced to the position of the Powell End Moraine in central

Ohio, depositing clay-rich till, whose clayeyness is believed to be due to inclusion of a considerable amount of lake clay (Goldthwait, 1959; Wenner, 1959; Forsyth, 1965). A small section of this moraine lies inside the southeastern boundary of the Sandusky River Basin area. After more retreat, perhaps back to the eastern end of Lake Erie, there was apparently another readvance, to the Wabash End Moraine (or farther north, to the southern boundary of the lake plain of northern Ohio), interpreted on the basis of even more clay-rich tills found at or north of that position (Goldthwait, White and Forsyth, 1961; Forsyth, 1965). Somehow, despite all these readvances, the ice was gone from Ohio,an overall retreat of more than 200 miles, in only about 4,000 years, a very speedy retreat for such a massive amount of ice.

Glacier-related lakes in central Ohio

Though large ice-dammed lakes were created in the Erie basin as the glacier retreated out of Ohio, they were not the first lakes formed along the edge of this ice in Ohio. The earliest known ice-dammed lakes were small, narrow lakes located north of the Fort Wayne End Moraine near Lima and held in on the north by the margin of the retreating glacier (Forsyth, 1969, 1973), but these small lakes did not extend as far east as the Sandusky River Basin area. Similar small, ice-marginal lakes may well have been present in the southern part of the Sandusky River Basin area at approximately the same time, but no clear-cut evidence for such lakes is known.

The oldest lake deposits recognized in the Sandusky River Basin area are those that were formed in the shallow lakes or marshes in the depressions in the criss-cross topographic pattern discussed earlier (created by east-west-oriented end moraines and north-south-oriented bedrock-controlled ridges) (Forsyth, 1973). Lake sediments reported in soils studies in Crawford County and marked by present-day marshes in Wyandot and Marion Counties (including Killdeer Plains) are fairly certainly of this origin. As indicated earlier, such "lakes" were probably no more than two or three feet deep, even during wetter periods, and probably dried up entirely during late-summer drouths.

Ice-dammed lakes in the Erie basin

Final retreat of the glacier out of Ohio removed the ice, but not its influence, from the state. Water pouring into the partially ice-free Erie basin (from streams, rain, and glacial meltwater) filled this basin with water deeper than occurs in Lake Erie today, because of the blocking of the Niagara outlet to the east by the retreating glacier. With this outlet blocked, water in the lake backed up, rising higher and higher and flooding much of the low land of northwestern Ohio, until the next lowest ice-free outlet was reached. This outlet, leading westward thorugh Fort Wayne into the Wabash drainage, was at 800 feet, so the level of this earliest lake was also 800 feet (it is the level of the outlet that determines the level of any lake), with the result that extensive areas in Ohio, Indiana, and Michigan were flooded by the lake waters. As the position of the ice edge shifted, in subsequent years, other outlets at different levels became available, each outlet resulting in a different water level or lake, each lake having a different name and being identified by its particular elevation. This series of lakes that formed in the ice-dammed Lake Erie basin are famous and have been discussed by many geologists (Leverett, 1902; Leverett and Taylor, 1915; Hough, 1958, 1963, 1966; Dreimanis, 1969; Calkin, 1970; Forsyth 1959, 1971a, 1973; Dorr and Eschman, 1970).

The first of these classic lakes, Lake Maumee I (at an elevation of 800 feet), was present when the ice edge still lay in northern Ohio. During the time when this lake was in existence, the ice edge advanced from out in the middle of the Erie basin southwestward to the position of the Defiance End Moraine (which was deposited at this time), for beaches of this lake (identified by their 800-foot elevation) are not found on or east of this moraine. In addition, lake clay and delta sands believed to have been formed in this lake occur beneath Defiance Moraine till near Tiffin (John R. Coash, personal communication, 1958; Echelbarger, 1976 - B.G.S.U. thesis in prep.). Waters of this initial lake drained westward through Fort Wayne, Indiana, into the Wabash River and thence into the Ohio and Mississippi Rivers.

With the retreat of the ice from the Defiance End Moraine, a lower outlet became available to the north, near Imlay in Michigan, so the level of the lake dropped abruptly to the level of this new outlet, forming Lake Maumee II (at 760 feet elevation). (Some people - Bleuer and Moore, 1972 - question whether the sand ridges called Maumee II really represent a separate lake or whether they really represent offshore bars formed contemporaneously with the subsequent, higher lake, Lake Maumee III, a controversy that has not yet been resolved.) Readvance of the glacier then blocked this lower outlet, causing the lake to rise and drain westward through the Fort Wayne outlet again, which by now had been lowered by erosion to an elevation of 780 feet, thus creating the new lake, Lake Maumee III, at an elevation of 780 feet. This rise in lake level flooded the older Maumee II beaches, causing them to become washed and lowered (a condition that would be interpreted differently by Bleuer and Moore, 1972). The Lake Maumee III beaches are one of the three highest, best-developed beaches in Ohio, highest because (1) they were made by relatively long-lived lake levels, and (2) they were never subsequently flooded. In the Sandusky River Basin area, they form clear-cut sand ridges extending to the northeast and northwest of Tiffin.

Another extensive retreat of the ice opened up a new, lower outlet in Michigan, this time probably around the thumb of Saganaw, resulting in Lake Arkona at an elevation of 715 feet. A following readvance then blocked this outlet, shifting the drainage to a higher but different outlet in Michigan, near Ubly, forming Lake Whittlesey at 735 feet elevation. The rise in lake level, like the earlier rise to the level of Maumee III, caused flooding and reworking of the preceeding lower beach deposits (Arkona). Although the actual outlet of Lake Whittlesey in Michigan was different from those of Lakes Maumee II and Arkona, waters flowing through all three outlets drained westward down the Grand River of Michigan into the early ice-dammed lakes in the Lake Michigan basin and on into the Mississippi River. The beaches of Lake Whittlesey are also among the three best developed - largest and steepest - in Ohio, especially in northeast Ohio, and form strong, well-marked sand ridges in the Sandusky River Basin area.

Another glacial retreat uncovered a still lower outlet across Michigan, resulting in the formation of Lake Warren, whose series of different levels (690, 680, 675 feet elevation) suggest that its outlet was being lowered by erosion during the time the lake was present. The beaches of Lake Warren are the third of the three strongly developed beaches in the Sandusky River Basin area, but they attain their greatest heights in northeast Ohio. Farther west, in the Sandusky River Basin area, Lake Warren beaches are low and discontinuous, apparently because the lake was so shallow here (figure 3).

A much lower lake level, associated with Lake Warren, is that of Lake Wayne (at 660 feet elevation), but there is some disagreement regarding both the time when this lake occurred, relative to the several stages of Lake Warren, and the location of its outlet; most people now consider it to have come after the 670-foot level of Lake Warren and also to have drained across Michigan (Dorr and Eschman, 1970; Calkin, 1970; Forsyth, 1973); it does not appear to have been an important lake stage anywhere in Ohio. Some very low discontinuous sand features below the levels of both Lakes Warren and Wayne are referred to different levels of Lake Lundy (640, 620, 615 feet elevation), but the records of these lake levels are very meager, probably because these stages were so short-lived and so shallow in Ohio (Dorr and Eschman, 1970; Forsyth, 1973).

Modern dating of these classic series of lakes shows that, despite the large number of lake levels and related ice-margin shifts, the entire history took place in a very short period of time - in 1,500 years or less. This is the length of the interval between the final time of retreat of the glacier from Ohio - about 14,000 years ago or less - and the oldest date for lake deposits in the Ontario basin to the north (which means that by then the ice had to have melted back north completely out of the Erie basin and north of the Niagara Falls outlet - a date now recognized to be about 12,000-12,500 years ago (Karrow, Clark, and Terasmae, 1961). For all the ice to have retreated far enough north for drainage from the early lake to flow east at such an early date, a date when isostatic recovery from the heavy weighing down of the land by the glacier in Canada (and the Niagara-outlet area) was so incomplete, was to presage a great flood, a subject considered in following pages.

Early Sandusky River

The Sandusky River was born in segments. When the ice margin had retreated from its position at the Wabash or Fort Wayne End Moraines, and small shallow lakes or marshes (including Killdeer, which was much more extensive then) had developed at several sites south of the Fort Wayne Moraine, normal drainage of the land began. Slopes were gentle, so erosion was slow and valleys did not immediately appear, but the drainage system that was evolving was the beginning of the Sandusky River system.

As the ice retreated still farther north, the small initial streams became extended northward across the newly exposed land, joining to form a single new, enlarging drainage system, that of the infant Sandusky. With continued ice retreat, the early Sandusky River extended itself still farther. When the first of the ice-dammed lakes, Lake Maumee I, was formed, lake clays were deposited near Tiffin, and the new little Sandusky River formed a sand-and-gravel delta into the lake just southeast of Tiffin. With the readvance of the ice at the culmination of Maumee I time, clayey glacial till was deposited over these lake sediments, materials now visible only in a very few road cuts or gravel pits or in shallow borings (John R. Coash, personal communication, 1958; Echelbarger, 1976-B.G.S.U. thesis in prep.).

With continued ice retreat, and with the evolution of the rest of the complex series of ice-dammed lakes in the Erie basin, the early Sandusky

River extended itself northward to the different lake shores, beginning with a considerably shorter drainage route than it has today and slowly extending this route as the lake shores became lower and farther away. The positions of the rest of the classic lakes in the Sandusky River Basin area are identified (figure 3) by the old beaches left by their lakes; indeed, some of the sand forming these old beaches may well have been washed into these lakes by the early Sandusky River.

The Great Flood

Eastward drainage was initiated when ice retreat finally exposed an outlet to the east lower in elevation than any to the west. Contrary to the older view, this change came only about 1,500 years after the formation of the first of the ice-dammed lakes in the Erie basin, an interpretation required by the discovery that ice-dammed lakes were already present in the Ontario basin to the north by 12,000-12,500 years ago (Karrow, Clark, and Terasmae, 1961). The moment when the glacial margin had finally retreated just far enough northeast to first permit release of the dammed-up waters in the Erie basin to the east must have been very exciting, a veritable flood (Lewis, Anderson, and Berti, 1966; Lewis, 1969; Forsyth, 1971a, 1973).

Judging by accounts of outflows of modern ice-dammed lakes, such as Lake George in Alaska (Alseth, 1952; Knudsen, 1951), when the lake waters first began to trickle past the edge of the ice, the water eroded and melted the ice, allowing more water to pass by, thus increasing the rate of erosion and melting until a tremendous flood of water poured out. Empty river-cut gorges at Lockport (Kindle and Taylor, 1913) and at other sites east of

Niagara Falls in western New York state, and deep river-less channels and very coarse gravel deposits farther east in New York (Hand and Muller, 1972) all attest to the fury of that flood (Forsyth, 1971a, 1973). When it was over, only two tiny ponds remained in the bottom of the Erie basin, one just west of the Niagara outlet, and one just west of a lake-bottom end moraine north of Erie, Pennsylvania (Hartley, 1961), the composite lake being called "spectacle lake" informally by Forsyth (1971a, 1973) and Early Lake Erie more formally by Hough (1958), Dreimanis (1969), and Lewis (Lewis Anderson, and Berti, 1966; Lewis, 1969).

The reason why the lake was so completely emptied of water is that Canada had been weighted down isostatically by the thick, heavy glacier, and had not yet risen back up to its original elevation. The area east of Lake Erie had become ice-free earlier, but isostatic forces work slowly, so the land had just begun to rise when the great flood took place. Thus Niagara Falls, the outlet and control of the level of Lake Erie, was lower then than it is today by about 150 feet (Lewis, 1969). Most of Lake Erie is not that deep, so such a low outlet, at the time of that great flood, caused the lake to drain out almost completely.

As the Niagara Falls area slowly rose, following deglaciation and the great flood, so did the level of the lake it controlled. Early rates of rise were fast - 30 feet per century - whereas modern rates are very slow - only about half an inch a century (Moore, 1948; Forsyth, 1973). It is this rise in the level of Lake Erie through the thousands of years since the glacier retreated that has caused the flooding of the lower ends of Lake Erie's southern tributaries. This rise, now at an infinitesimal rate, has had no effect whatsoever on the recent high water-levels in Lake Erie, which are a result of generally excessive amounts of rain and reduced rates of evaporation throughout the several years previous to the high-water years.

Later Sandusky River

With the emptying of most of Lake Erie by the great flood, all rivers tributary to it, including the early Sandusky River, became extended out across the exposed lake floor. Presumably river joined river - the Detroit, the Maumee, the Sandusky, and others - creating a combined, moderately integrated drainage system leading northeastward across the old lake bottom to the westernmost of the two small ponds left by the flood. This little pond, dammed by the small lake-bottom end moraine north of Erie, became lower as time went on, as a channel was eroded through the soft till of the moraine, a channel which has been recognized in modern lake-bottom studies. (Hartley, 1961).

The post-flood Sandusky River was longer than it had ever been before or would be again. Its valley extended from its southernmost headwaters (the same headwaters it had had as the glacier was retreating from Ohio and as it has today) northward to the present Sandusky Bay and thence northeastward through that Bay and out across the newly exposed lake bottom to the middle of the lake basin, passing by rocky hills destined to become the Erie Islands. It was probably in about the middle of the lake basin where it joined a major stream from the west, the combined Maumee-Detroit river, created by the extension and mergence of those rivers out across the lake bottom.

The Maumee-Detroit river, joined by the early Sandusky River and many other tributaries, must have been a very big river, flowing slowly eastward across the relatively flat lake floor. Lowering of the small western pond into which it fed, as the outlet through the moraine was eroded, caused this large Maumee-Detroit-Sandusky river to extend its valley even a little more, across the narrow belt of land exposed by the retreating margin of the pond. These combined rivers were as long at this time as they were ever to be; isostatic uplift of the northern, Canadian shore and of the Niagara outlet was going on rapidly and, as the Niagara outlet rose, so did the level of the lake, causing flooding that first merged the two ponds and then expanded westward across the earlier abandoned lake floor and back up first the combined and then the separate valleys of the Maumee, Detroit, and Sandusky (and other) Rivers.

Isostatic recovery of Lake Erie and the Xerothermic Interval

Isostatic uplift of the glacially depressed land on the north shore of Lake Erie had undoubtedly begun before the time of the great flood. The curve recording this isostatic recovery, based on many radiocarbon dates of subaerial organic remains obtained from within the lake basin area but below present water level (Lewis, 1969), starts long after uplift began, but at a time when recovery was still relatively rapid. The initial rate of rise of the lake level following the great flood was about 30 feet a century, but this rate became less through time, as the rate of isostatic recovery decreased, and today it is going on at a rate of only about half an inch a century (Moore, 1948; and interpreted from recovery curves figured by Lewis, 1969, and by Forsyth, 1973).

The best evidence for this uplift is the fact that beaches of the earlier ice-dammed lakes are tilted; beaches of Lake Whittlesey, for example, which occur consistently at an elevation of 735 feet in Ohio, become higher as they are traced to the northeast, so that they occur at 780 feet elevation in easternmost Pennsylvania (Schooler, 1974) and at 900-910 feet elevation near Buffalo (Calkin, 1970). This tilting of beaches (Leverett and Taylor, 1915; Hough, 1958), which must have been horizontal when they were formed, records the amount of isostatic uplift at the northeast end of Lake Erie. Little or no such isostatic recovery is recorded south of the lake in Ohio (and none in the Sandusky River Basin area), probably because the ice had been too thin there to have weighed down the land very much. (The remarkably fast retreat of the last glacier from Ohio, which took only 4,000 years, is probably a result of this thinness of the glacier, which meant that its wastage took place rapidly.)

The present barely recordable rate of uplift is not really perceptible and has not been the reason for the recent high lake levels. These high levels, which have occurred at a number of times in the last 115 years, as demonstrated by records published by the Lake Survey Center (1972), were created by increased precipitation and reduced evaporation in the years previous to the high-water years.

The recovery curve is not a smooth curve, but has superimposed on it an irregularity, or "wobble", recording a reduced rate of rise between about 10,000 and 4,000 years ago, and a very fast rate of rise between 4,000 and 3,500 years ago. This aberration is real and is based entirely on the radiocarbon dates of subaerial organic materials obtained from below modern lake level, and has been interpreted to represent the effects on the rising lake level of the Xerothermic Interval, a period of warmer, dryer climate following the retreat of the glacier (Sears, 1941, 1942b, 1948; Ogden, 1965; Forsyth, 1973). Such a climate could well lower lake level substantially (note the marked effect of a much shorter period of wetter climate recently!), and no other reasonable hypothesis has been found.

Postglacial record of life

The record of the repopulation of Ohio and of the Sandusky River Basin area following deglaciation is very incomplete. The best data on revegetation come from pollen records (Sears, 1930, 1941, 1942a, 1942b, 1948; Potter, 1947; Ogden, 1965, 1966, 1967), though some information has been obtained from macroscopic plant remains as well (Burns, 1958; Goldthwait, 1958). The pollen record itself is incomplete, because sites with pollen information are scattered, pollen data are generally given only for genera (and in many cases only for tree genera), and pollen records are not true records of the local vegetation (some pollen breaks down and is lost; the pollen of some species blows more readily than that of others; some species produce more pollen than others, etc. - Ogden, 1965, and personal communication, 1960). Despite these inadequacies, pollen data are the best source of information on the nature and sequence of the postglacial vegetation, and the basic record they reveal is generally accepted (Sears, 1930, 1941, 1942a, 1942b, 1948; Potter, 1947, Ogden, 1965, 1966, 1967).

This record shows an initial dominance of spruce and fir (*Picea* and *Abies*) (Sears, 1930, 1941, 1942a, 1948; Potter, 1948; Ogden, 1965, 1966; and also Burns, 1958), which lasted until about 10,000 years ago (Ogden, 1965, 1967). With the decline in spruce and fir came a brief dominance of pine (*Pinus*) (a dominance that may not be real, since pine produces so much more pollen per cone than do most other conifers) and nonarboreal species, followed by a long period characterized by deciduous trees.

This pine dominance has been used by Sears (1941, 1942a) to identify the beginning of the warmer, dryer Xerothermic Interval (Sears, 1942b) that continued, after a period when more mesic beech (*Fagus)* occurred, into a time characterized by oak and hickory (*Quercus* and *Carya)*. Indeed, Sears (1942a, 1948) developed a sequence of five zones within the overall pollen sequence, which correlates well with results of pollen studies elsewhere in northern United States (Ogden, 1965). These five zones, arranged with the oldest at the bottom, are:

V - Mesophytic deciduous zone - beach, maple (*Acer)* (and locally hemlock (*Tsuga)*

IV - Xerophytic deciduous zone - oak, hickory (and prairies)

III - Mesophytic deciduous zone - beech, hemlock

II - Xerophytic conifer zone - pine

I - Cold, humid conifer zone - spruce, fir

The lower part of this sequence is apparent in Sears' pollen studies of the Bucyrus Bog (two miles east of Bucyrus)(Sears, 1930), but the upper part of this sequence is absent there, so Sears drew first on Mud Lake Bog (in Ashland County)(Sears, 1941) and then on pollen records elsewhere in northeastern United States (Sears, 1942a, 1948) to demonstrate the universality of this pollen sequence and the implied climatic history.

The pollen profile at Silver Lake (west of Bellefontaine and about 25 miles southwest of the southwestern boundary of the Sandusky River Basin area) studied by Ogden (1966) reveals a similar sequence. This begins with spruce and fir, and is followed by an oak-pine-nonarboreal pollen zone, followed by a long interval of deciduous species: oak and hickory (e.g., more xeric; oak, hickory, beech, maple, elm (*Ulmus)*, and walnut (*Juglans)* (e.g., more mesic); oak, hickory, nonarboreal (more xeric again); oak hickory, beech, maple, ash (*Fraxinus)*, elm, and walnut (more mesic again), and concluding with a sharp increase in ragweed (Ambrosiae) that identifies the beginning of the extensive clearing of forests by the early European settlers (Ogden, 1966). Overall, all these pollen data appear to record an initial amelioration of the glacial climate, followed by a warmer, dryer interval (the Xerothermic), within which there seems to have been a period during which conditions were less xeric. In addition, these data reveal the record of repopulation by individual genera on this newly deglaciated landscape.

Wherever special conditions occurred, special groups of plants were present. Low wet sites, once the early cold-climate conifers (black spruce - *Picea mariana)* had disappeared, were probably characterized by swamp-forest species: elm, white ash (*Fraxinus americana)*, red maple (*Acer rubrum)*, poplar (*Populus)*, and even willow (*Salix)*. Sites with exposed-limestone substrates, following the disappearance of the conifers (mainly white spruce - *Picea glauca* - fir, and jack pine - *Pinus banksiana)*, probably had more xeric, limestone-related species present (Forsyth, 1971b): chinquapin oak (*Quercus muehlenbergii)*, white cedar (*Thuja occidentalis)*, red cedar (*Juniperus virginiana)*, hackberry (*Celtis occidentalis)*,hop-hornbeam (*Ostrya virginiana)*, blue ash (*Fraxinus quadrangulata)*, plus sugar maple (*Acer saccharum)* (Thieret, 1964; Hamilton and Forsyth, 1972; Forsyth 1971b, 1973, and results of unpublished studies of woods on limestone substrates in upper Michigan).

Locally prairies, mostly wet prairies (Sears, 1926; Gordon, 1969; Forsyth, 1970), were present in northwest Ohio, in the easternmost extent of the famous Prairie Peninsula (Transeau, 1935; Wright, 1968), developed mainly where the ground was too wet for trees (at least in the critical spring-early summer season). The greatest extent of such prairies in the Sandusky River Basin area occurred in the marshy depressions in the criss-cross topographic pattern described earlier, though small prairie remnants were also present near Carey in the west, near Flat Rock in the east, and northwest of Fremont (Gordon, 1966). These wet prairies (or marshes) were characterized by wet species of grasses, sedges, and some composites, mainly reed grass (*Phragmites)*, blue-joint grass (*Calamagrostis)*, bulrushes and many other sedges (*Scirpus, Cyperus, Eleocharis)*, and, in areas of deeper, more permanent water, slough grass (*Spartina)*, cattail (*Typha)*, pickerel week (*Pontederia)*, and bur weed (*Sparganium)* (Sears, 1926; Gordon, 1969; Mayfield, 1969; Ronald L. Stuckey, personal communication 1970). Though these wet prairies and marshes are local and scattered throughout the Sandusky River Basin area, they represent a fascinating variant of the original vegetation here.

With revegetation of the land, repopulation of the area by animals could take place. Records of animals which invaded this newly deglaciated landscape are limited and mostly of the larger vertebrates. Information on the invertebrates and smaller vertebrates is almost entirely in the form of their present occurrence. Centainly all the species of smaller animals, vertebrates and invertebrates, that are found in the area today represent postglacial invasions which took place as soon as the climate was warm enough and adequate habitat was available. Records given by Mayfield (1969) for the Black Swamp near Toledo give as good a view as does any publication of the smaller animals that must have been present in the Sandusky River Basin area at that time.

Records of the larger animals are mainly in the form of remains of skeletal fragments which have been dug up: of mastodons, mammoths, ground sloths, giant beaver, elk, and bison (Hay, 1923; Forsyth, 1963), of which the first four apparently became extinct about 10,000 years ago (J. G. Ogden, III, personal communication, 1960). Whether or not these extinctions were the result of predation by early human hunters is controversial; some feel that these hunters were mainly responsible for these extinctions, while almost everyone agrees that extensive decimation of these species was caused by these early men (Martin, 1967). Following the demise of these big vertebrates, forests still contained extensive populations of deer, elk, bison, and smaller animals, with muskrat and normal-sized beavers in the streams and lakes, all animals which have suffered far more from the destruction of their habitats by modern man than they did from hunting by the prehistoric peoples (Mayfield, 1969).

Early man, himself, was one of the animals to move into Ohio, and into the Sandusky River Basin area, once the ice was gone. The earliest men, the more primitive hunters (called PalaeoIndians - Potter, 1968), invaded Ohio about as soon as did the early plants and animals; once the land was revegetated, animals came in, followed almost immediately by early man. Records of the PalaeoIndians are mainly in the form of scattered fluted points found in southern Ohio, but some lanceolate Plano points have been found in northwestern Ohio (Potter, 1968). The later hunters, the Archaic peoples, left many ancient axe-heads, spear points, and tools in this part of the state (David M. Stothers, personal communication, 1973). The next prehistoric peoples, the mound-builders (Adena and Hopewell, the latter being more skilled and artistic), left their mounds mainly in more southern parts of Ohio, but culturally distinct mound-builders (called Middle Woodland) were also present in the northern part of the state (David M. Stothers, personal communication, 1973). With increasing numbers of prehistoric peoples in Ohio came a change from mound-builders to the Late Mississippian peoples, with an Erie-focus culture in this area characterized by lake-margin communities of people who used pottery and bows and arrows, and who buried their dead in rectangular graves (Potter, 1968; David M. Stothers, personal communication, 1973). It was these latest peoples who comprised the Indians found here by the early European pioneers.

Modern Sandusky River

With the rising level of Lake Erie, as isostatic recovery of the Niagara outlet continued, the extended Maumee-Detroit-Sandusky River became drowned and foreshortened more and more until eventually the confluences were flooded, and the rivers became separate. The Sandusky River then became still shorter and shorter, as the lake waters continued to rise, though at a decreasing rate (as the rate of isostatic rise decreased), until the present state of almost equilibrium was reached, with the lake shore where it is today, and the lake flooding back up the Sandusky River almost to Fremont.

Geological processes now active in the Sandusky River Basin area are those observable today: river erosion (mainly during floods), sedimentation (both along the rivers and in Sandusky Bay), river flooding (with waters submerging terrestrial substrates), and upland erosion (by surface wash and raindrops). Except for the flood-originated actions, these processes are generally going on very slowly. Other modern processes are those of man, who is not only an active agent himself, but increases erosion and sedimentation by destruction of woodlands and plowing of sod. In addition, man actually changes locations of streams and contributes strange and undesirable materials to the river waters.

Thus, through a complex geologic history, different geologic materials have been formed or exposed, which have become the substrates of the modern Sandusky Basin area organisms, organisms influenced (and sometimes destroyed) by the natural geologic processes active in the drainage basin. This geologic history also describes the events and geologic setting affecting the earlier biota of this area, from which the modern organisms have evolved. No consideration of these modern organisms can be complete without a careful analysis and evaluation of the geologic setting in which they are found.

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ABSTRACT

DISTRIBUTION OF NON-POINT SOURCES OF PHOSPHOROUS AND SEDIMENT IN THE SANDUSKY RIVER BASIN

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The average annual transport of soluble orthophosphorus, total phosphorous and suspended solids has been calculated at each of five U.S. Geological Survey stream gages in the Sandusky Basin. Calculations were based on numerous instantaneous loading measurements taken between July, 1969 and November, 1974. For each station, weighted mean concentrations were obtained by dividing total flow volume during the periods of observation. Average annual transport was then calculated by multiplying weighted mean concentrations by average annual flows.

The 4 values following each stream gage listed below represent consecutively the annual transport of total phosphorous (as P) in short tons, the phosphorous runoff coefficient in lbs/sq mi/yr. The values for each stream gage were: Tymochtee - 88,769, 48,000 and 210; Bucyrus - 51, 1150, 14,000 and 157; Upper Sandusky - 148, 993, 58, 300 and 196; Mexico - 314, 811, 199,000 and 257; and Tiffin - 509, 813, 271,000 and 217.

The drainage areas above each of the five stream gages define five subbasins. For each subbasin, annual point source inputs of phophorous were determined and, and along with phosphorous inputs from upstream subbasins, subtracted from the annual output from the subbasin. This provided an estimate of non-source runoff coefficients in lbs of total phosphorous/acre/yr were: Tymochtee, 1.20; Bucyrus, 0.22; Upper Sandusky, 1.25; Mexico, 0.88; and Tiffin, 0.93. The annual yield of total phosphorous from non-point sources in the basin was 390 tons of 77% of the total annual yeild. For the entire 1251 sq mi basin, the average non-point source phosphorous runoff coefficient was 0.98 lbs/acre/yr, an extremely high value in comparison with other values in the literature. Most of this phosphorous is associated with clay particles which dominate the suspended solids loaded in the stream.

THE DISTRIBUTION OF NON-POINT SOURCES OF PHOSPHORUS AND SEDIMENT IN THE SANDUSKY RIVER BASIN

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Much effort is currently directed toward reducing phosphorus loading into Lake Erie from its tributary streams. This effort is concentrated on the phosphorus originating at municipal sewage treatment plants because the appropriate technology exists and because municipal sewage apparently is the major source of phosphorus enrichment in Lake Erie (U.S. Department of Interior 1968).

As more detailed studies of nutrient loading from tributaries into Lake Erie are being completed, it is becoming evident that large amounts of phosphorus originating from general land use activities are also being transported into the lake. We have shown that a minimum of 75% of the total phosphorus delivered to Lake Erie from the Sandusky Basin must originate from rural non-point sources (Baker and Kramer, 1973). Furthermore, the observed runoff coefficient for total phosphorus from rural non-point sources (1.03 kg/ha/yr) was 2.4 times larger than the value used to estimate phosphorus yields from rural land in North Central Ohio in early phosphorus-balance calculations for Lake Erie.

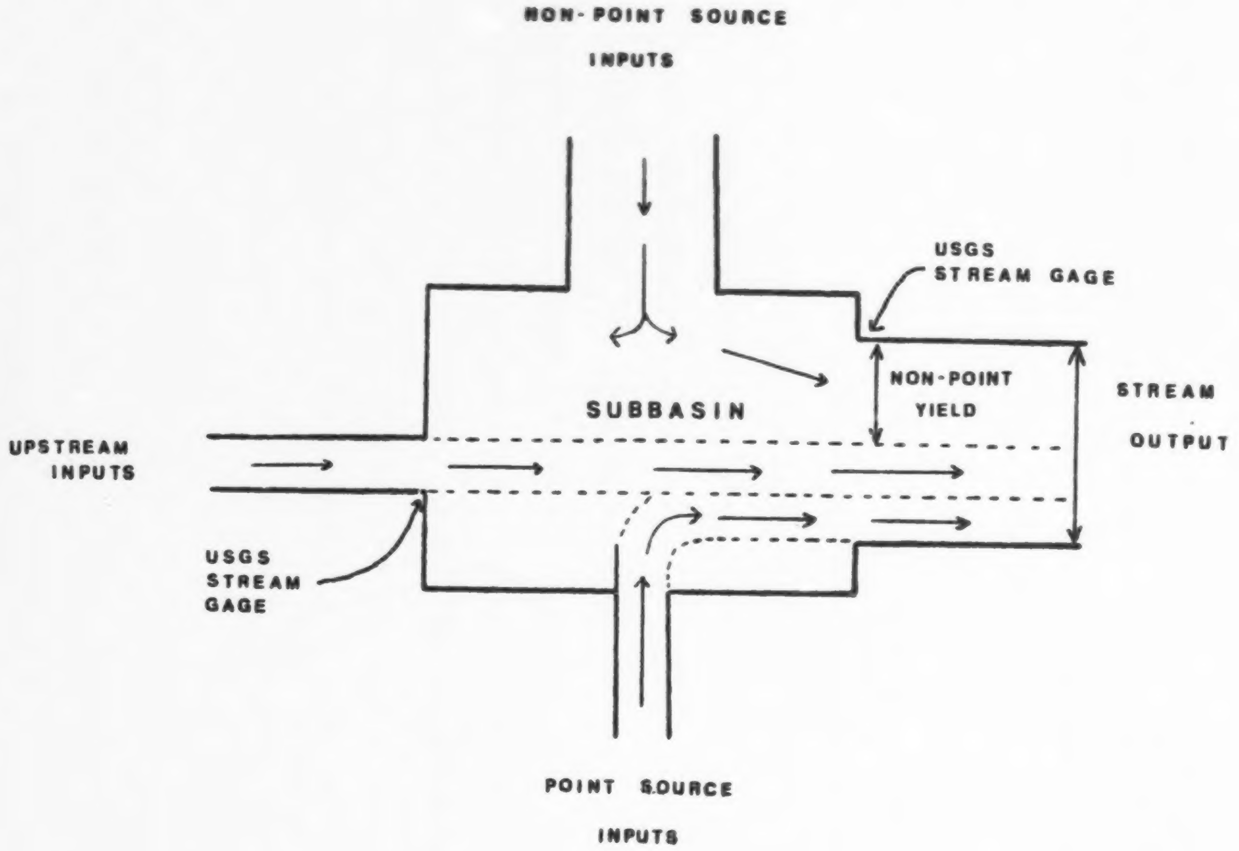
This report contains a more detailed study of the sources of phosphorus and sediments within the Sandusky River Basin. Phosphorus and sediment balances for five subbasins are developed. These data reflect the status of phosphorus sources before the onset of phosphorus removal measures at the municipal sewage treatment plants in the basin. Studies currently in progress are directly evaluating the effects of municipal phosphorus removal on the transport of phosphorus from this river basin into Lake Erie and on the water quality of the stream.

METHODS

Model for calculating non-point source yields

We have calculated non-point source yields of phosphorus and sediments from individual subbasins of the Sandusky River Basin using the model illustrated in Figure 1. Materials in the stream system within any subbasin can originate from: (1) streams flowing into the subbasin, i.e. upstream inputs; (2) point source inputs within the subbasin; or (3) non-point source inputs within the subbasin. The material yield from any subbasin consists solely of the stream output. By assuming that all of the material entering the subbasin from upstream inputs and point source inputs is transported through the subbasin, we can calculate the *minimum yield* from non-point sources by subtracting the upstream inputs and the point source inputs from the total output. This calculation represents the *minimum yield* from non-point sources because, if either upstream or point source inputs are permanently lost from the flowing river system within the subbasin, a larger portion of the total stream output would have to be accounted for by non-point sources. Such losses could occur by deposition on flood plains or behind dams or by biological pathways. The model assumes that on an annual basis, there is no net accumulation of phosphorus or sediments in the river system.

The assumptions of the model can be explained in terms of delivery ratios. Delivery ratio is normally defined as the ratio of the sediment yield from a drainage area to the gross erosion rate within that drainage area, expressed as a percentage (Gottschalk, 1964). It is convenient to extend this concept to include phosphorus from both non-point and point sources and also to apply the general concept of output-to-input ratio to characterize


NON-POINT SOURCE
INPUTS
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YIELD
SUBBASIN
STREAM
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UPSTREAM
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USGS
STREAM
GAGE
POINT SOURCE
INPUTS

Figure 1 Model for the calculation of non-point source yields of materials from subbasins of the Sandusky River Basin.

transport through sections of the stream. For upstream inputs of both sediment and phosphorus, delivery ratios through the subbasins are assumed to be 100%. Likewise the delivery ratio of phosphorus from point sources is assumed to be 100%. No assumptions are made for the delivery ratio of materials originating from non-point sources. Consequently, the gross erosion rate within a subbasin cannot be calculated from the sediment yield of that subbasin. Also non-point source "inputs" of phosphorus cannot be calculated from the non-point source yield of phosphorus.

In applying the above model, accurate measurements of material transport in the river on the input and output sides of each subbasin are required. Existing U.S. Geological Survey Stream Gages provide locations where the necessary stream flow data are available for calculations of material transport. The locations of these stream gages in the basin determine the size and shape of the subbasins. In the Sandusky River Basin, five continuously recording stream gages are present. The locations of these stream gages and the resulting subbasins which they delineate are shown in Figure 2. The area, population, and physical characteristics of each subbasin are shown in Table 1.

Sample collection

The data presented in this report were obtained between January 1969 and December 1974. Periods of high, medium and low flows during all seasons of the year are included.

Before March 1974, all samples were collected using plastic buckets lowered from bridges near the stream gage sites. Stream flow at each of the sites is turbulent, especially during periods of high flow. Particle size analysis of samples from the Sandusky River indicates that more than 96% of the sediment is in the clay and silt fractions, having fall diameters less

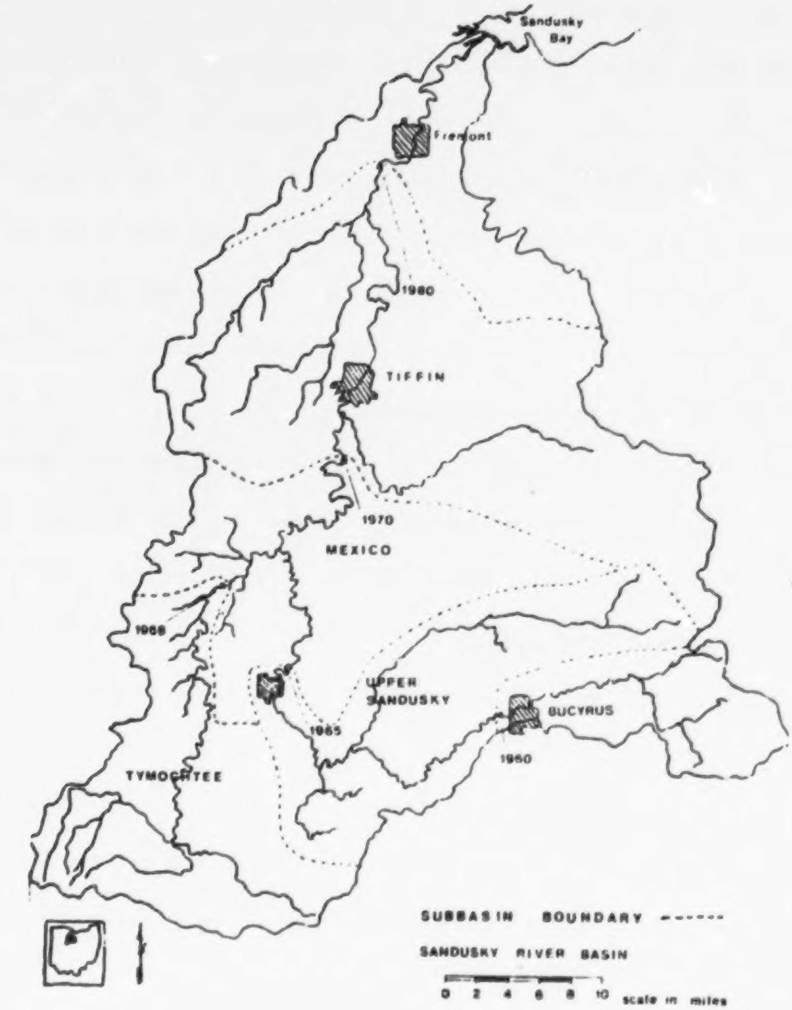
Sandusky Bay
Fremont
1980
TIFFIN
1970
MEXICO
1969
UPPER SANDUSKY
1965
BUCYRUS
1950
TYMOCHTEE
SUBBASIN BOUNDARY ------
SANDUSKY RIVER BASIN
0 2 4 6 8 10 scale in miles

Figure 2 Map of the Sandusky River Basin showing the names, shapes and locations of the individual subbasins. The identification numbers of the U.S. Geological Survey stream gages which comprise the output/input stations for each basin are also shown.

Table 1: Area, Population and Physical Features of Subbasins of the Sandusky River Basin*

Subbasin	Subbasin Area km^2	Population Total #/km^2	Density Rural #/km^2	General Description
Tymochtee	593	11.0	11.0	Bedrock-- Silurean Age dolomite and limestone; topography — relatively flat till plain traversed by terminal moraines; soils -- high lime glacial till.
Bucyrus	230	112.4	29.5	Bedrock -- Mississippian Age shales and sandstones; topography -- relatively flat till plains traversed by terminal moraines; soils -- high lime glacial till.
Upper Sandusky	542	26.4	16.0	Bedrock — Devonian and Silurean Age dolomite and limestone; topography -- relatively flat till plains traversed by terminal moraines; soils -- both high and low lime glacial tills.
Mexico	640	19.7	14.1	Bedrock -- Devonian and Silurean Age dolomite and limestone; topography -- relatively flat till plains traversed by terminal moraines; soils -- mostly high lime glacial tills.
Tiffin	1235	38.0	19.0	Bedrock -- Devonian and Silurean Age dolomite and limestone; topography - mostly flat to gently rolling lake plains; soils-- dark colored, poorly drained clay soils in northern part, high lime glacial till in southern part.

* Metric-English Conversion:
1 square kilometer = 0.386 square miles

than 0.031 mm (Ohio Department of Natural Resources, 1966; U.S. Department of Interior, 1974). Given the turbulence and the fine particle size, grab samples should yield essentially the same results as samples obtained with depth-integrating techniques.

In order to obtain more detailed information on changing phosphorus and sediment concentrations during runoff events, three automatic sequential samplers were put into operation in March 1974. These samplers were located at the gage stations where continuous monitors for dissolved oxygen, temperature, pH and conductivity are in operation (Upper Sandusky, Tymochtee and Mexico). The pumps of the automatic samplers withdrew water from the probe tanks of the continuous monitors. High volume pumps provide a continuous flow of river water through the probe tanks. Sediment and phosphorus analyses on samples collected from the probe tanks agreed very closely with similar analyses on grab samples from the stream. The automatic samplers were set to collect discrete samples at 6 to 8 hour intervals. The samplers contained enough bottles for one week of sampling.

With the exception of samples obtained by the automatic samplers, almost all of the samples were analyzed within 24 hours of the time of collection. In most cases, samples were collected in the morning and analyzed the same afternoon. Consequently, no preservation techniques were employed. Preservatives were not used in bottles within the automatic samplers. In tests of samples obtained during winter and spring runoff events, dissolved orthophosphate showed little change during one week of storage within the sampler. Mercuric chloride was tested as a preservative for these samples. It provided no advantage over unpreserved samples and its use was discontinued.

Analytical methods

Both total phosphorus (Storet #0065) and dissolved orthophosphate (Storet #00671) were measured by the single reagent method as outlined in *Methods for Analysis of Water and Wastes* (U.S. Environmental Protection Agency, 1971). Before 1974, all of the colorimetry was done using a Klett-Summerson colorimeter. Since that date, a Technicon Autoanalyzer II System has been used. For total phosphorus, samples with high suspended sediments were filtered through glass-fiber filters after the persulfate digestion. The digestion was done in an autoclave and the samples were filtered while still hot.

Suspended sediments (Storet #00530) were also done according to the methods outlined in the above manual. A well-mixed sample was filtered through a preweighed glass-fiber filter (Reeve Angel 934AH) and the residue retained on the filter was dried to a constant weight at 103-105 degrees C.

Flow measurements

At the time of sample collection, the river stage was either measured with a wire weight gage or read from the tape punch equipment in the gage house. The U.S. Geological Survey provided a rating table for each station for converting river stages into flows. Where the automatic samplers were used, the river stages at the time of sample collection were obtained from printouts of hourly gage height data supplied by the U.S. Geological Survey.

RESULTS

Figure 3 illustrates the typical changes in sediment and phosphorus concentrations which occur during runoff events. These samples were collected

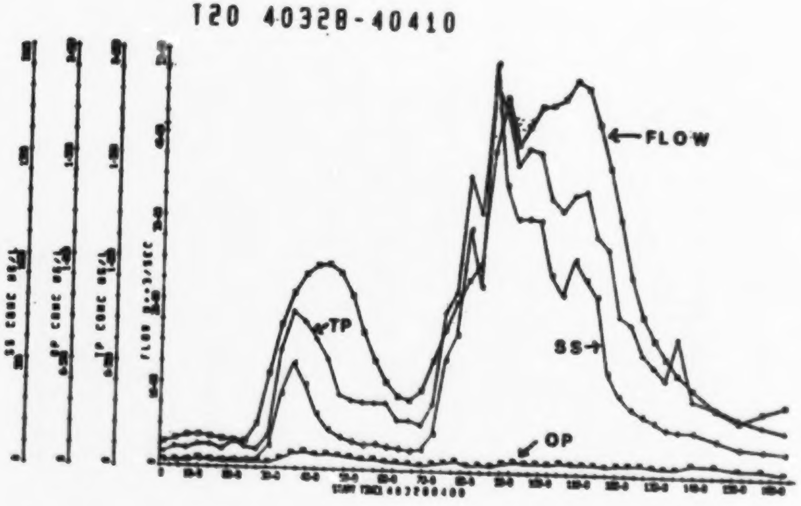

Figure 3 Hydrographs, sediment graphs and chemigraphs for two runoff events at the Tymochtee stream gage occurring between March 28 and April 10, 1974. Samples were collected at 6 hour intervals. The time base is in units of 2 hour increments beginning at the starting time of 400 hours March 28, 1974.

at six-hour intervals during two runoff events at the Tymochtee stream gage in March and April 1974. The concentrations of both suspended sediments and total phosphorus increased rapidly during the initial phases of the runoff events. Concentrations of both of these started to decrease before the peak flows were reached. The "fine structure" of the total phosphorus and suspended solids curves are very similar. Although much lower in absolute value, the concentrations of dissolved orthophosphorus at this station also increased during the runoff events.

To estimate the mean annual transport at each gage station, using data of the type illustrated in Figure 3, we calculated weighted mean concentrations of total phosphorus, soluble phosphorus and suspended solids. The weighted mean concentrations were obtained by dividing the observed total loading by the observed total flow (table 2). Total loadings and total flows were calculated using the mid-interval technique, as employed by the U.S. Geological Survey at their sediment-transport stations (Porterfield, 1972.) For example, if samples were collected at six-hour intervals, the instantaneous flux rate and flow rate at the time of sample collection are assumed to characterize the stream conditions for the three hours before and after the sample collection. The total transport during the six-hour period was calculated and summed with similar calculations for all of the other samples collected at that stream gage. This method of calculating weighted mean concentrations reduces the bias which could be introduced when samples are collected at six-hour intervals during runoff events but at 24-hour intervals during lower flows.

Table 2: Data Base for Calculations of Weighted Mean Concentrations of Orthophosphorus (O.P.), Total Phosphorus (T.P.) and Suspended Sediments (S.S.) at U.S. Geological Survey Stream Gages in the Sandusky River Basin *

Station	Parameter	Number of Measurements	Mean Flow During Sampling m^3/s	Observed Total Loading metric tons	Observed Total Flow $10^8 m^3$	Weighted Mean Concentration mg/l
Tymochtee	O.P.	563	4.61	10.56	1.48	0.071
	T.P.	593	5.46	92.57	1.86	0.498
	S.S.	533	5.68	45,550	1.68	271
Bucyrus	O.P.	309	2.56	8.35	0.36	0.230
	T.P.	303	2.42	18.81	0.33	0.563
	S.S.	316	2.71	6,766	0.39	173
Upper Sandusky	O.P.	570	7.46	37.0	2.66	0.139
	T.P.	554	8.68	180.9	3.12	0.580
	S.S.	536	9.40	88,450	3.01	294.0
Mexico	O.P.	336	20.4	59.2	6.08	0.098
	T.P.	360	23.0	410.5	7.29	0.563
	S.S.	314	24.9	242,900	6.83	356
Tiffin **	O.P.	144	37.1	65.0	6.38	0.102
	T.P.	203	62.6	731.2	13.3	0.550
	S.S.	132	58.3	263,500	9.00	292.5

* Metric-English conversions: 1 cubic meter/second = 35.3 cubic feet/second;
1 metric ton = 1.102 short tons.

** The Tiffin gage station is located at Tindall Bridge just south of Fremont.

The data base used to calculate weighted mean concentrations at each stream gage station is summarized in Table 2. In addition to the number of individual samples, the observed total loading and the observed total flow, the mean flow during the sampling period is shown. This value was obtained by dividing the total observed flow by the total time over which the total loading and total flow were calculated. Comparison of the mean flow during the sampling period with the mean flow for the period of record allows evaluation of sampling bias.

The mean annual transport of materials at each stream gage was obtained by multiplying the mean annual flow by the weighted mean concentrations. These calculations are shown in Table 3. The values of the mean annual flow are based on the entire period of hydrological record at each station and were obtained from *Water Quality Records for Ohio, Part I* (U.S. Department of Interior, 1974).

Table 4 shows the calculations of non-point source yields of total phosphorus for each subbasin, using the model previously described. Point source inputs of total phosphorus within each subbasin were obtained by using a population equivalent of 2.1 kg/person/yr and the populations served by sewer collection systems within each subbasin. The value, 2.1 kg/person/yr, was obtained from studies of the effluents from the sewage treatment plants of the two largest cities (Tiffin and Bucyrus) and a detailed study of combined sewer overflows in Bucyrus (Burgess and Niple Ltd., 1969; Baker and Kramer, 1973.)

The yields of suspended solids for each subbasin are shown in Table 5. For suspended solids, point source inputs are disregarded. Since soluble orthophosphate is rapidly converted into the organic and/or bound forms,

Table 3: Calculation of Mean Annual Transport of Ortho Phosphorus, Total Phosphorus and Suspended Solids at U.S. Geological Survey Stream Gages in the Sandusky River Basin

Station	Parameter	Weighted Mean Concentration mg/1	Mean Annual Flow m3/s	Mean Annual Transport metric tons
Tymochtee	O.P.	0.071	5.098	11.4
	T.P.	0.499		80.1
	S.S.	271		43,570.
Bucyrus	O.P.	0.230	2.353	17.1
	T.P.	0.563		41.8
	S.S.	173		12,860.
Upper Sandusky	O.P.	0.139	6.768	29.7
	T.P.	0.580		123.8
	S.S.	294		62,690.
Mexico	O.P.	0.098	16.14	49.9
	T.P.	0.563		286.6
	S.S.	356		181,000.
Tiffin *	O.P.	0.102	26.65	85.7
	T.P.	0.550		462.2
	S.S.	292.5		245,800.

* The "Tiffin" Gage Station is at Tindall Bridge just south of Fremont.

Table 4: Calculation of Non-point Source Yields of Total Phosphorus for Subbasins Within the Sandusky River Basin

Subbasin	Stream Output t/yr	Stream Input t/yr	Point Source Inputs* t/yr	Non-point Source Yield t/yr
Tymochtee	80.1	--	--	80.1
Bucyrus	41.8	--	40.2	1.6
Upper Sandusky	123.8	41.8	11.9	70.1
Mexico	286.6	203.9	7.4	75.3
Tiffin	462.2	286.6	49.3	126.3
Total for Basin	--	--	102.8	353.4
Source as Percent	--	--	23.5	76.5

* Based on 2.1 kg/person/yr (4.6 lbs/person/yr) for sewered population in each subbasin.

Table 5: Calculation of Suspended Sediment Yields for Subbasins in the Sandusky River Basin

Subbasin	Stream Output 10^3 metric tons	Stream Input 10^3 metric tons	Subbasin Yield 10^3 metric tons
Tymochtee	43.37	--	43.57
Bucyrus	12.86	--	12.86
Upper Sandusky	62.69	12.86	49.83
Mexico	181.0	106.26	74.74
Tiffin	245.8	181.0	64.80

the assumption of a 100% delivery ratio from upstream and point source inputs could not be made. Consequently, subbasin yields for soluble orthophosphate have not been calculated.

In order to compare the total phosphorus and suspended sediment transport at the stream gages and the non-point source yields from the subbasins, the results are presented as runoff coefficients in Table 6. For the gage stations, the mean annual transport at each station has been divided by the total drainage area upstream from that station. For the subbasins, the non-point source yields of phosphorus and suspended sediments from each subbasin were divided by the area of that subbasin. For both the stream gage stations and the subbasins, the ratios of phosphorus yield (in kg) to suspended sediments (in tons) are also shown.

DISCUSSION

The method of calculating non-point source yields of phosphorus and sediments used in this study depends on accurate estimates of the mean annual transport at stream gages. Weighted mean concentrations can provide such estimates only when the data used in the calculation of the weighted mean are proportionally representative of the long-term transport characteristics of the stream. Since the bulk of material transport occurs during periods of high flow, it is especially critical that the data include many measurements at high flow conditions. Comparison of the mean flow during the sampling period (table 2) with the mean annual flow for the period of record (table 3) indicates that our sampling was, in fact, biased toward high flow conditions. To avoid such flow bias would require many additional samples at low flows.

Table 6: Runoff Coefficients for Total Phosphorus and Suspended Sediments at Stream Gages and for Subbasins *

Stream Gage or Subbasin	Stream Gages			Subbasins		
	T.P. kg/ha/yr	S.S. tons/ha/yr	Ratio kg P/ton SS	T.P. n-p** kg/ha/yr	S.S. tons/ha/yr	Ratio kg P/ton SS
Tymochtee	1.35	.73	1.84	1.35	.73	1.84
Bucyrus	1.82	.56	3.25	.07	.56	.125
Upper Sandusky	1.60	.81	1.97	1.29	.92	1.40
Mexico	1.43	.90	1.51	1.18	1.17	1.01
Tiffin	1.43	.76	1.88	1.02	.52	1.96

* Metric-English conversions: 1 kilgram/hectare/year = 0.89 pounds/acre/year;
1 metric ton/hectare/year = 0.45 short tons/acre/year.

** Non-point source phosphorus only.

These samples would have little effect on either the total observed load or the total observed flow, and consequently would have little effect on the weighted mean concentration. Other more complex methods of using these data to estimate mean annual transport have been examined and yield similar results.

These studies confirm earlier findings of the dominance of non-point sources of phosphorus in the loading from the Sandusky River Basin into Lake Erie. Furthermore, the calculated non-point source phosphorus yields are large in all but one of the subbasins in the Sandusky Basin. For all of the subbasins except Bucyrus, the calculated minimum non-point source yields exceeded 1 kg/ha/yr. A survey of previous studies of nutrient transport from agricultural watersheds conducted for the International Reference Group on Great Lakes Pollution from Land Use Activities found an average yield of 0.38 kg/ha/yr (International Joint Commission, 1974, Part A6). A summary of another literature survey showed average and maximum runoff coefficients of 0.3 and 1.0 kg/ha/yr respectively from agricultural land (U.S. Environmental Protection Agency, 1974). As noted by Ryden et al (1973), there is a great need for detailed long-term studies of phosphorus yields from streams draining agricultural watersheds. There are relativley few studies available that allow direct comparison between the non-point source phosphorus yields for the Sandusky subbasins and yields from other areas of comparable size and land use.

In comparison to other river basins in Northwestern Ohio, the Sandusky is not unique in its high phosphorus yields. During January through May 1975, measurements of nutrient and sediment yields at the stream gages nearest Lake Erie in the Maumee, Portage, Sandusky and Huron River Basins gave runoff coefficients for total phosphorus of 1.59, 1.25, 1.29 and 1.05 kg/ha/yr respectively (U.S. Army Corps of Engineers, 1975). The methods used in that study were the same as described here, although the yields listed above include both point and non-point sources of phosphorus. It should be noted that at least some point source control efforts were in operation in each river basin during the above study.

It is noteworthy that the Tymochtee subbasin had the highest non-point source phosphorus runoff coefficient. This subbasin contains no municipal point sources and the rural population density is lower than that of any other subbasin. Given the low population density, septic tank runoff could not account for much of the non-point source phosphorus yield, even if the delivery ratio of phosphorus from septic tanks to streams was high. The possibility that feedlot runoff is contributing significantly to the phosphorus yield from this subbasin has not been directly investigated. If feedlot runoff acts like a point source, giving rise to increasing phosphorus concentrations as the stream flow decreases, this source would be insignificant because the phosphorus concentrations are lowest at low flows. The very close correlation between sediment and total phosphorus concentrations (figure 3) suggests surface runoff as the major source of the phosphorus. Part of the runoff could come from feedlots.

The unrealistically low non-point source runoff coefficient of total phosphorus from the Bucyrus subbasin has several possible explanations. Underestimation of total transport at the Bucyrus output station, overestimation of point source inputs within the subbasin and/or less than 100% delivery of total phosphorus from point source inputs through the subbasin could account for the low value. The extremely low phosphorus/sediment ratio for the Bucyrus subbasin (table 6) also indicates that the non-point source yield of phosphorus for this subbasin is being underestimated.

The data for the Bucyrus gage are based on daily grab samples. As the smallest subbasin in area, runoff events would have the shortest duration. Since an automatic sampler was not used at this station, it is possible that peak concentrations and peak flows have been missed.

Since the stream gage at Bucyrus is only 1 km downstream from the treatment plant effluent, a point source delivery ratio significantly less than 100% could only be occurring from phosphorus originating at the Crestline sewage treatment plant, which is located about 35 km upstream from the Bucyrus stream gage. It is well known that phosphorus originating from point sources can at least temporarily move onto the stream bottom (Keup, 1968). The magnitude of this instream phosphorus deposition for the Sandusky River is illustrated in a separate paper in this symposium (Baker and Kramer, 1975). If these phosphorus losses become permanent, then the delivery ratio from point sources of phosphorus could drop well below 100%.

Delivery ratios less than 100% in the other three subbasins containing point sources could explain the lower phosphorus runoff coefficients calculated for those subbasins than for the Tymochtee subbasin (table 6). If the delivery ratio from inland point sources to Lake Erie is significantly less than 100%, the effectiveness of phosphorus removal at inland treatment plants in reducing loading into the lake will be less than for comparable removal at point sources emptying directly into the lake.

The question of the delivery ratio of phosphorus from inland point sources to Lake Erie is closely related to the question of the delivery ratio of sediments thorugh subbasins along the Sandusky. In calculating subbasin yields for suspended sediments (table 5), we assumed that all of the sediment entering a subbasin from upstream sources was part of the output from the subbasin. Neither deposition behind low-head dams on the stream nor deposition on flood plains was assumed to be significant. If phosphorus from point sources becomes associated with sediment, either while temporarily on the stream bottom or while in transit during runoff events, then the subsequent delivery of that phosphorus to Lake Erie will depend on the delivery of the sediments to the Lake. In other words, a 100% delivery of phosphorus from point sources may depend on a 100% delivery of sediment through the stream. Literature dealing with the adsorption of soluble orthophosphate onto sediment particles has recently been reviewed by Ryden, et al (1973).

In most river basins the delivery ratio of sediments decreases as the area of the basin increases (Gottschaulk, 1964; Great Lakes Basin Commission, 1975). This is generally reflected as a decrease in sediment runoff coefficients with increasing areas of drainage basins. This trend is not apparent in the Sandusky, at least as far as the Mexico stream gage, since the sediment runoff coefficients at stream gages increase from Bucyrus to Mexico (table 6). Previous estimates of sediment yields for Northwestern Ohio streams, based on calculated gross erosion rates and sediment delivery ratios obtained by extrapolation from studies of other river basins, resulted in significant underestimations of the observed sediment yields (Great Lakes Basin Commission, 1975). The discrepancy for the Maumee Basin (480,000 short tons/yr estimated versus 1,179,000 short tons/yr observed) was attributed to the delivery ratio component of the estimates. Possibly, the streams of Northwestern Ohio have unusually high delivery ratios of sediments. It should also be noted that according to estimates by the Pollution from Land Use Activities Reference Group, the river basins of Northwestern Ohio contribute 39% of the total agriculturally derived sediment yield delivered from the United States to the Great Lakes (International Joint Commission, 1974).

One serious deficiency in the concept of delivery ratios, as normally conceived, is that it neglects particle sizes. Obviously, the delivery ratio for smaller particles is greater than for larger particles, everything else being equal. Yet the small particles,i.e. clays, bear the bulk of the exchange and binding sites for phosphorus or other potential pollutants. Consequently, the delivery ratio for non-point source phosphorus could be higher than for sediments. Furthermore, areas with higher gross erosion rates likely have larger average particle sizes and lower average delivery ratios to Lake Erie than areas with lower rates of gross erosion. The implications of this, relative to achieving significant reductions in the yields of sediments and non-point source phosphorus to Lake Erie,may be very significant. Sediment yields may not decrease in proportion to the reduction in gross erosion rates because of differences in delivery ratios from areas of high and low gross erosion rates.

As noted earlier, particle size analyses of sediments at the stream gages in the Sandusky Basin by the U.S. Geological Survey indicate the dominance of clay-sized particles even at the stations with the smallest drainage areas. This provides further justification for the assumption of 100% delivery of upstream sediments through the subbasins. Given this assumption, the resulting subbasin yields of suspended sediments, as calculated in Table 5 and expressed in Table 6, do show a general relationship to subbasin landscape characteristics. The Mexico subbasin, with a sediment yield of 1.17 t/ha/yr, includes a large part of the terminal moraine which transects the Sandusky Basin in that area. With its relatively greater verticle relief, higher gross erosion rates and larger average particle sizes of the sediments from this subbasin may be expected. The phosphorus-to-sediment ratio is lower in the Mexico subbasin than in the others, with the exception of Bucyrus. In contrast, the Tiffin subbasin, which has the lowest unit area sediment yield, includes a large portion of flat lake-plain soils. The sediment derived from this area does, however, have the highest non-point source phosphorus-to-sediment ratio. This could be explained by the finer particle size associated with sediments derived from these intensively cultivated lake-plain soils. The low unit-area sediment yield from the Bucyrus subbasin could be associated, either directly or indirectly, with the fact that the subbasin also has the highest rural population density. The Upper Sandusky and Tymochtee subbasins are intermediate to those described above. More detailed correlation of subbasin yields with land capability and land-use characteristics will be undertaken upon completion of the comprehensive soil surveys currently in progress.

Given the magnitude of the non-point source yields of phosphorus from the Sandusky Basin (and other Northwestern Ohio streams), questions of the chemical forms and biological availability of the phosphorus associated with suspended sediments derived from sheet erosion become very important. The status of these questions has recently been reviewed (Ryden et al, 1973) and additional study is scheduled as part of Task D, of the Pollution from Land Use Activities Reference Group, International Joint Commission. The behavior of sediment-bound phosphorus in newly constructed upground reservoirs in Northwestern Ohio is also currently under investigation (Kramer and Baker, 1975).

CONCLUSIONS

The data indicate that non-point source phosphorus loading is more uniformly distributed over the landscape than is sediment loading. Excluding the Bucyrus subbasin, the phosphorus runoff coefficients ranged from 1.02 to 1.35 kg/ha/yr. Sediment yields ranged from 0.52 to 1.17 tons/ha/yr. We propose that differences in delivery ratios between the fine clays that bind phosphorus and the sediment fraction as a whole (clays and larger particles) can account for this observation. If correct, a consequence would be that non-point source phosphorus-control efforts need to be evaluated independently of erosion-control efforts, since the latter are primarily directed at areas of critical erosion problems. Controlling non-point phosphorus yields may prove even more difficult than controlling sediment yields in Northwestern Ohio.

The assumptions concerning delivery ratios of phosphorus and sediments, upon which is based the model for calculating non-point source yields from subbasins, are discussed in some detail. A better understanding of delivery ratios from streams in Northwestern Ohio will be essential for planning effective and efficient control measures for phosphorus originating from land-use activities. The magnitude of the phosphorus loading form non-point sources also underscores the need for evaluating the biological activity of phosphorus adsorbed to sediments originating from surface runoff.

ACKNOWLEDGEMENTS

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ABSTRACT

SOIL SURVEYS AS A TOOL IN STUDIES OF NONPOINT SOURCES OF STREAM SEDIMENT

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Soil surveys of the entire Sandusky River Basin will be available within 5 to 10 years. They will provide factual, on-site observations of the soil as well as predictions of responses to various kinds of land use and management. Soil surveys have been used by USDA-SCS for about 30 years in conservation planning on farms in the river basin. At present about one-third of the basin has completed soil maps. By 1980 about four-fifths of the Sandusky River Basin will have soil maps available.

Control of soil erosion is only one of many uses being made of soil maps. The universal soil loss equation considers the soil factors of texture, organic matter, structure, and permeability in arriving at specific degrees of soil erodibility (K). Permissable soil losses (T) are also determined by knowledge of soil formation provided by soil surveys. In addition to making predictions of soil loss, the soil survey makes an inventory of soil losses due to erosion under the past 150 years of cultivation.

Analysis of soil survey data for Crawford County indicates there are five distinct groups of soils based on degree of soil erosion. Soils with little or no soil loss are more than one-half of the land area. Soils that have lost up to 6 inches of topsoil are another one-third of the land area. Lesser acreages of soils that appear to have lost 6 to 12 inches of soil by erosion, account for large amounts of total sediments reaching streams. Soils on floodplains have accumulation of soil sediment but also have active bank erosion.

The areas of sloping to steep soils have an estimated annual soil loss under 150 years of cultivation of about 9 tons/acre/year. Overall about 42 percent of all past soil losses have occured from only 7.5 percent of the land area in the county. This data focuses attention on fairly limited areas of land that are the major nonpoint sources of stream sediment.

SOIL SURVEYS AS A TOOL IN CONTROL OF SOIL SEDIMENT

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INTRODUCTION

The soil survey is an acre by acre field investigation and mapping of variation in soil properties that affect plant growth, water movement, and the use of land. The survey identifies the kind and sequence of soil layers in the zone of interaction between earth, water, atmosphere and life (to a depth of about five feet). Features such as soil texture, structure, color, reaction (pH), slope, and geologic setting are noted in the process of classifying the soil into one of the many standard soil series. Once the soil series is known, ratings of soil response to use and management can be made based on experience and research on this soil at other locations.

The USDA Soil Conservation Service (SCS) has been using soil surveys for conservation planning on farms in the Sandusky River Basin since about 1945. During the past five years surveys of Crawford and Seneca Counties have been started through local cost share agreements with county commissioners. At present about one-third of the basin has a completed soil survey. All of the Crawford County maps are available along with a report (Steiger, 1975) published by the Ohio Department of Natural Resources Division of Lands and Soil (DLS). The eastern part of Seneca County also has maps completed by the DLS. A survey of Wyandot County by SCS has just begun. By 1980 about four-fifths of the basin will have soil maps available.

METHODS

Prediction of soil erodibility, based on soil surveys, is the key to the method of erosion control followed by the Soil Conservation Service. Soil erosion is a function of several soil properties. The universal soil loss equation includes these in the soil erodibility (K) factor. Properties that affect erodibility include surface texture, structure, organic matter content, and infiltration rate. All of these properties are evaluated for each soil series in Ohio and a numerical value for K has been derived. The soil survey also provides information on slope gradient and length, which are also part of the soil loss equation.

In addition to the predictions of soil erodibility, the soil survey provides a record of accelerated erosion that has occurred under cultivation. This is indicated by comparison of soil profiles in uncultivated (woodland) sites with similar soils in cultivated fields. Indicators of soil loss are: (1) changes in soil texture and color that reflect selective removal of fines and organic matter, followed by incorporation of subsoil into the surface layer; (2) net reduction in the thickness of the surface layer and total soil rooting depth; (3) accumulations of surface soil at the base of slopes; and (4) formation of rills and gullies during rainstorms. In Crawford County soils are grouped into four categories based on degree of soil loss: (1) non eroded, (2) slightly eroded, (3) moderate to severely eroded, and (4) sediment deposition.

DISCUSSION

The analysis of data from the Crawford County Soil Survey indicates that over half of the soils have lost less than one inch of topsoil by erosion. (See Tables 1 and 2.) These are poorly drained soils on nearly level land. Runoff is slow and much of the rainfall percolates through the soil into drainage tile. What erosion does occur is associated with the drainage network. Ditch bank erosion, surface water and tile outlet points are the most common point sources. Dominant in this group of soils are Condit, Lenawee, Luray, Pewamo, and Tiro.

Undulating soils with short gentle slopes are about one-third of the land area in Crawford County. These soils are estimated to have lost about 0 to 6 inches of topsoil after 150 years of cultivation. Some of the sediment is carried only short distances before being deposited on level land. Most of the soils in this group have restricted drainage as well as an erosion hazard. Recent trends toward more intensive row crops and larger field size has increased runoff and erosion on these soils. Bennington, Blount, Cardington, and Glynwood are the dominant soils of this group. Soil is moved by impact and rill erosion. Average rate of soil loss is estimated at 2 tons/acre/year.

On sloping to steep land along stream valleys are soils that have lost from 6 to 12 inches of topsoil in the past 150 years of cultivation. During the past 20 to 30 years many of these soils were not used for cropland due to crop adjustment (land retirement) program of USDA. Recently, however, these fields are again being planted to row crops. Gully formation as well as impact and rill erosion occur on these soils. About 5 percent of the land is

TABLE 1

Degree and extent of erosion of soils in Crawford County, Ohio

Group	Description	Acreage	% of Land Area
1	Level, Non Eroded	143,350	55.4
2	Undulating, Slight Erosion	84,772	32.8
3	Sloping to Steep, Moderate to Severe Erosion	13,836	5.3
4	Urban, Moderate to Severe Erosion	5,905	2.3
5	Floodplain, Deposition and Bank Erosion	10,747	4.2
	TOTAL	258,560	100.0

TABLE 2

Estimated soil loss over past 150 years

Group	Average Soil Loss	Rate Tons/Ac/Yr	Total Tons	% of Total
1	1 inch	0.5	10.7×10^6	17.0
2	0 to 6 inches	2.0	25.9×10^6	41.0
3	6 to 12 inches	9.0	18.7×10^6	29.5
4	0 to 18 inches	10.8	8.0×10^6	12.5
5	?	?	?	
Total Average		1.6 t/ac (1024 t/mi^2/yr)	63.3×10^6	100.0

in this group dominated by Alexandria, Cardington, Glynwood, and Hennepin soils. Rate of soil loss is estimated at 9 tons/acre/year.

Floodplain lands along streams have evidence of soil sedimentation from periods of stream overflow. In addition, however, the stream channel is actively meandering by erosion of banks during peak flow. It is not evident from the soil survey whether floodplains are agrading or degrading in Crawford County. About 4 percent of the land is on floodplains with Lobdell, Medway, Shoals, and Sloan soils dominant.

Land altered by residential, commercial or mine development accounts for about 2 percent of area of Crawford County. These areas probably have soil losses approaching 10 tons/acre/year but no observation of soil loss is possible from soil survey data.

In summary, only about 17 percent of total soil loss is occurring on nearly level soils that are over one-half of the land area. About 41 percent is occurring on gently sloping soils under cultivation which are one-third of the land area. The remaining 42 percent of soil losses occurs on only 7.5 percent of the land, that is sloping to steep cropland or urban land. Average estimated soil loss is about 1.6 ton/acre/year or 1024 $t/mi^2/yr$.

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ABSTRACT

EROSION CONTROL AND AGRICULTURE IN THE SANDUSKY RIVER BASIN

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Most of the land area of the Sandusky River Basin is devoted to agricultural use. This use involves changing the type and amount of vegetative cover on the soil. This change usually effects the quantity and quality of the water that runs off of the land and into the drainage ways. The effect is greater as the slope increases.

Unlike most pollutants, silt from farmland is not a waste or by-product that has been dumped or discarded, but a valuable resource that is lost unintentionally while the crop is being produced. Farmers have long recognized if erosion is not kept within certain limits, the topsoil will be depleted over a period. Erosion can be broken down into three major types: 1. gully, 2. streambank, 3. sheet and rill. All are non-point sources of sediment with no feasible means of measuring the volume from each field. However, through the years of research, the Soil Conservation Service has developed a method of predicting the amount of soil lost from sloping land by sheet and rill erosion. It is known as the Universal Soil Loss Equation -- A = RKLSCP, where:

A = Estimated Annual Soil Loss
R = Rainfall Factor
K = Soil Erodibility Factor
L = Slope Length Factor
S = Slope Gradient Factor
C = Crop Management Factor
P = Erosion Control Factor

While this formula predicts the amount of soil lost from a given field, it does not predict the yield of sediment to the stream. Much of the silt is deposited on the level fields at the base of the slope before it gets into the waterway.

When enough research is done to give us an estimated yield for each soil type, then we will be able to predict sediment production.

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ABSTRACT

OHIO EPA WATER QUALITY STUDIES IN THE SANDUSKY RIVER BASIN

G. L. MARTIN

Ohio Environmental Protection Agency, Bowling Green, Ohio

Water quality studies were conducted by the OEPA in the Sandusky River between May and December, 1974. These studies were conducted as a part of the State continuing planning process for water quality management, which is required under section 303(e) of PL 92-500, the Federal Water Pollution Control Act Amendments of 1972.

The emphasis of the Ohio EPA monitoring program in the Sandusky River Basin has been on the main stem and near the mouths of the major tributaries. Most of the sampling effort was concentrated on moderate to low flow regimes rather than peak discharges, consequently, the monitoring program has emphasized the effects of non-point source pollution. The major water quality problems encountered in the study were primarily related to inadequate municipal sewage treatment facilities and combined sewer overflows. The areas most severely affected were: Paramour Creek below Crestline, Spring Run below Carey, Muskellunge Creek below Fremont, and the Sandusky River below Bucyrus.

Water quality violations recorded most frequently were for fecal coliform bacteria, dissolved oxygen, and ammonia. Infrequent violations were also recorded for phenols, copper, and mercury; however, no apparent trends were observed. The presence of heavy metal violations indicates the need to conduct a sediment sampling program within the basin to study the extent and severity of heavy metal pollution.

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OHIO EPA WATER QUALITY STUDIES IN THE SANDUSKY RIVER BASIN

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INTRODUCTION

The Ohio EPA water quality studies in the Sandusky River Basin are part of the State's continuing planning process for water quality management, which is required under Section 303(e) of the Federal Water Pollution Control Act Amendments of 1972.

The continuing planning process is intended to provide the State with water quality assessment and program management information necessary to make centralized, coordinated water quality management decisions and to encourage water quality objectives which take into account overall State policies and programs, including those for land use and other related natural resources. The planning process should:

(1) insure that applicable water quality standards are attained,

(2) specify the requirements and schedule the completion of basin plans for all waters,

(3) insure public participation in the development of the planning process and basin plans, and

(4) provide a basis upon which the State's overall program of water pollution abatement will be developed.

The development of the State's program of water pollution abatement is accomplished by forming an annual strategy, which is based upon basin plans where they are completed and upon available information where the plans are not completed. The annual strategy assists the State in directing resources against water quality problems on a priority basis and in establishing a coordinated schedule of action for water pollution abatement. In additon, the annual strategy is a means of reporting progress in achieving program targets and scheduled milestones.

Without a Federally approved planning process, no state will be allowed to operate a permit system. The national system used to regulate dischargers to waters of the State is known as the National Pollutant Discharge Elimination System (N.P.D.E.S.). This permit system is designed to develop and enforce consistent nationwide treatment and effluent standards with legally agreed upon time tables to meet these standards.

For the State continuing planning process to receive Federal approval, the State is required to maintain an adequate monitoring program to gather accurate information of water quality, and to tailor abatement programs to individual stream conditions. Water quality data are gathered primarily through studies of individual basins.

Intensive basin surveys were conducted by the Northwest District Office of the Ohio EPA in the Huron, Portage, and Sandusky River Basins during 1974. Preliminary sampling of the Sandusky River Basin began in late April and ended in December; however, most of the sampling effort was concentrated on moderate to low flow regimes between June and October.

The basic objectives of the Sandusky River Basin Study were:

(1) to determine the severity and extent of pollution within the Basin,

(2) to locate sources of pollution within the Basin, and

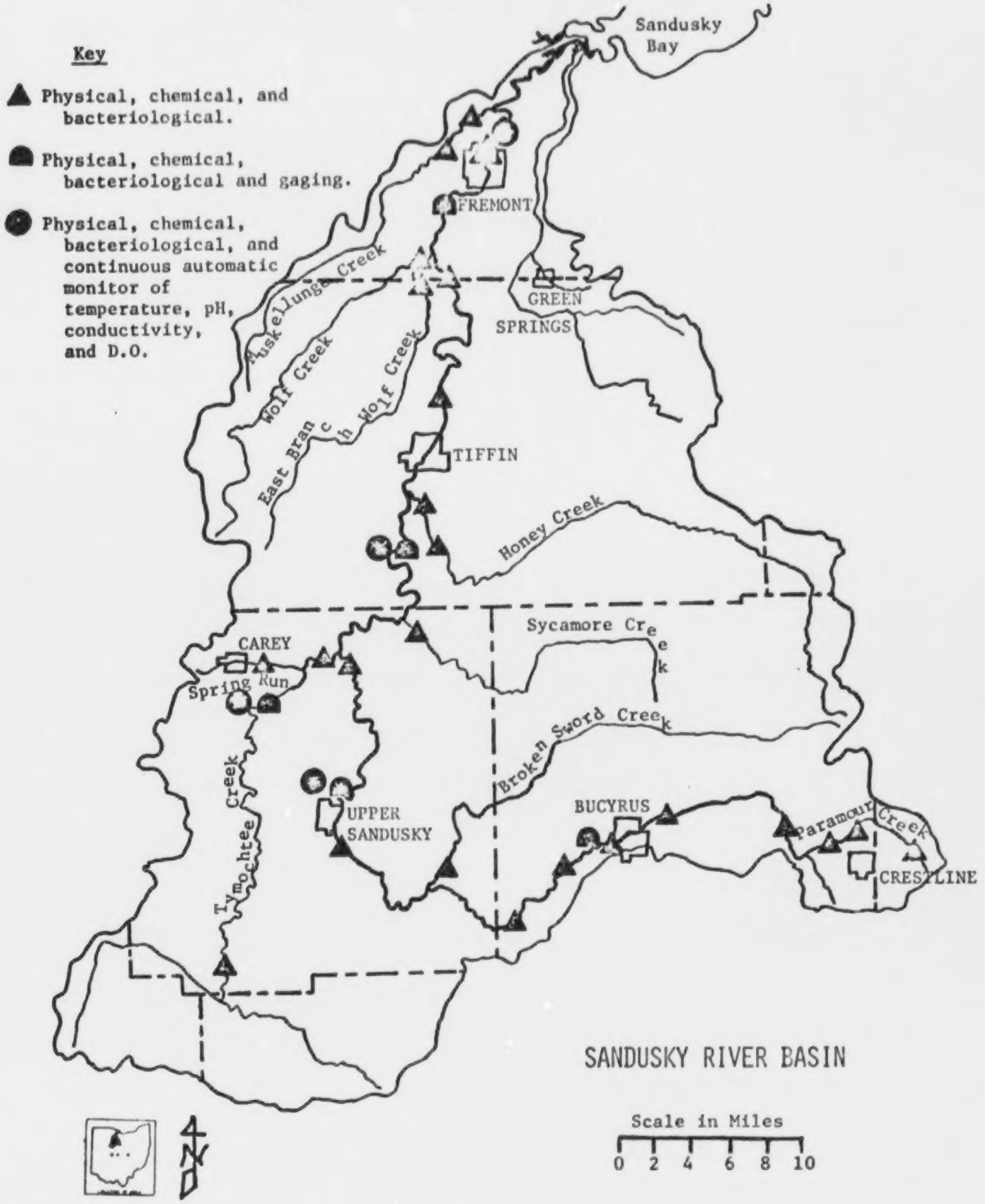
(3) to establish a body of base-line data on which future studies can be based and to suggest areas in which such studies would be most useful.

Water quality sampling stations were, in general, selected at points above and below the major municipalities and near the mouths of the major tributaries. Sixteen locations were sampled on the main stem of the Sandusky River and 18 locations were sampled on the following tributaries: Broken Sword Creek, Honey Creek, Muskellunge Creek, Paramour Creek, Sycamore Creek, Tymochtee Creek, and Wolf Creek. Figure 1 indicates the locations of the sampling stations.

As mentioned before, most of the sampling effort during 1974 concentrated on moderate to low flow regimes rather than on peak discharges; consequently, the monitoring program has emphasized the effects of point-source pollution rather than the effects of agricultural and urban runoff. There are 15 municipal and semi-public dischargers to the Sandusky River Basin in addition to 14 municipal water treatment plants and 27 direct industrial dischargers. Several additional industries discharge to municipal sewage treatment plant systems.

Four of the municipal sewage treatment plants have discharges exceeding one million gallons per day; while five have discharges between 0.1 and 1 MGD and six have discharges less than 0.1 MGD. Of the 27 industrial dischargers, seven are involved in food processing and six are involved in limestone processing. Five of the industries have discharges exceeding 1 MGD and three have discharges between 0.1 and 1 MGD.

Figure 1 Water Quality Sampling Stations


Key
▲ Physical, chemical, and bacteriological.
Physical, chemical, bacteriological and gaging.
● Physical, chemical, bacteriological, and continuous automatic monitor of temperature, pH, conductivity, and D.O.
Sandusky Bay
FREMONT
Muskellunge Creek
Wolf Creek
East Branch Wolf Creek
GREEN SPRINGS
TIFFIN
Honey Creek
Sycamore Creek
CAREY
Spring Run
Broken Sword Creek
Tymochtee Creek
UPPER SANDUSKY
BUCYRUS
Paramour Creek
CRESTLINE
SANDUSKY RIVER BASIN
Scale in Miles
0 2 4 6 8 10
N

Seven municipal water treatment plants have a discharge to the Basin. Six water treatment plants obtain their water from the Sandusky River or its tributaries.

METHODS

Water quality monitoring stations were generally selected to determine the effects of the major municipalities and the major tributaries on the water quality of the Sandusky River. Grab samples were collected by the staff of the Ohio EPA, Northwest District Office, from bridges or by wading out to midstream. No allowance was made for time of travel when collecting samples.

Samples for solids, biochemical oxygen demand, foaming agents (MBAS), nutrients, phenols, cyanide, and heavy metals were collected in plastic containers. Bacterial samples were collected in sterile glass containers. Glass containers were used to collect samples for oil and grease. All samples were placed in iced coolers immediately after collection and transported to the laboratory. Phenols were preserved with $CuSO_4$, cyanide with NaOH, and heavy metals with HNO_3. Preservation of other parameters had not been initiated during the sampling period.

All samples were analyzed by the Ohio Department of Health. Samples were analyzed in accordance with test procedures specified by the U.S. EPA under 40 CFS 136.[1] Dissolved oxygen and temperature were measured in the field with a YSI model 54 oxygen meter.

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[1] The list of approved test procedures was published in the Federal Register, Volume 38, Number 199 - Tuesday, October 16, 1974, pp. 28757-28760.

RESULTS

The major water quality problems encountered in the Sandusky River Basin were primarily related to inadequate municipal sewage treatment facilities and combined sewer overflows. The Sandusky River below Bucyrus, Muskellunge Creek at Fremont, Spring Run below Carey, and Paramour Creek below Crestline were found to be heavily polluted by inadequately treated municipal wastes. These municipal wastes are from both industrial and domestic sources. The locations of the major problem areas are shown in Figure 2.

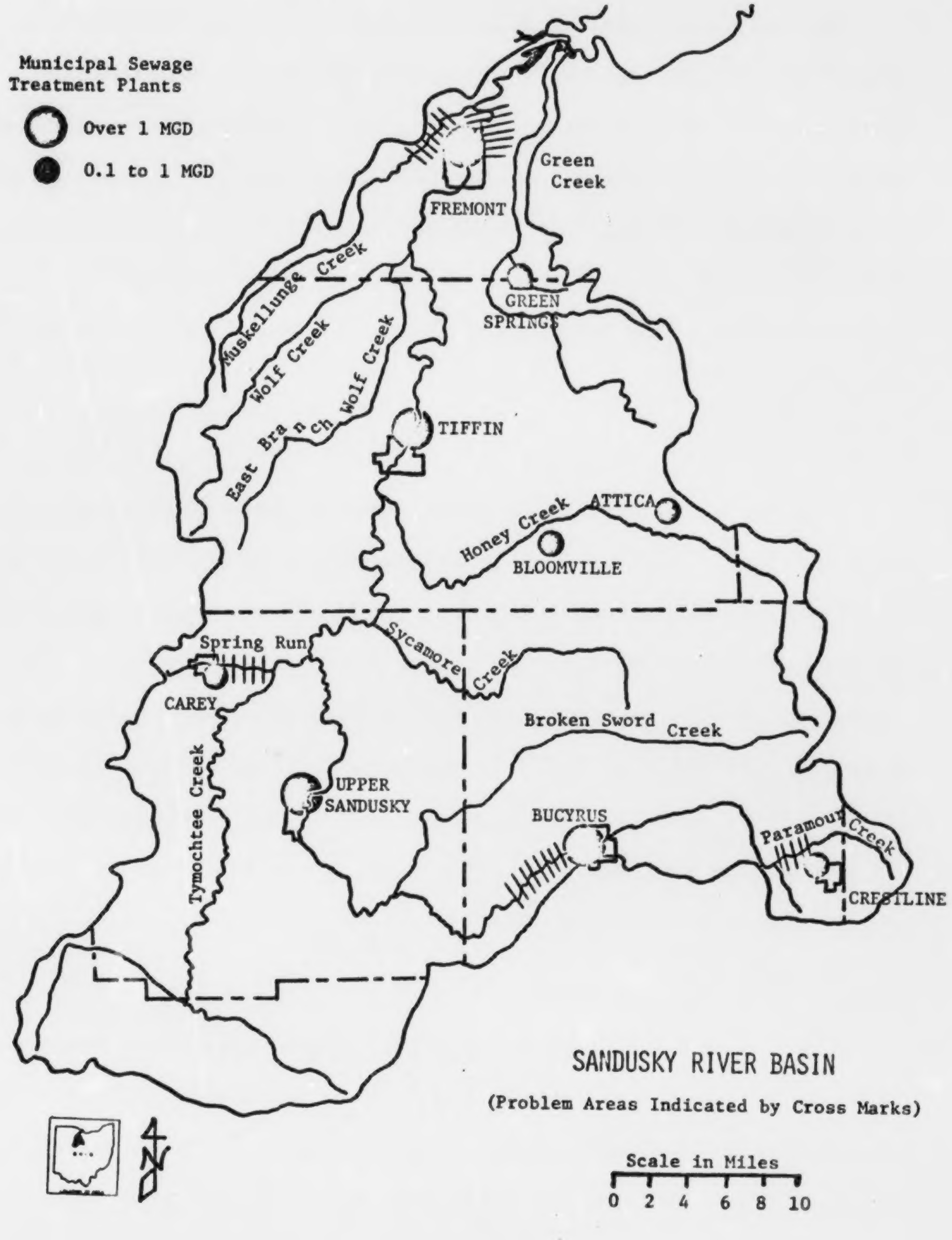
Paramour Creek below Crestline

Inadequate treatment of sewage at Crestline seriously degraded the water quality in Paramour Creek. Water quality violations were recorded for dissolved oxygen, ammonia, foaming agents (MBAS). phenols, and fecal coliform bacteria. The dissolved oxygen concentration was measured at 0.3 mg/l or lower on several occasions, ammonia-nitrogen was measured at values greater than 6 mg/l in several samples, and fecal coliform bacteria levels were consistently greater than 15,000/100 ml. Crestline has improved its sewage treatment facilities since 1974. These improvements should improve the water quality of Paramour Creek.

Sandusky River below Bucyrus

Water Quality Standards for dissolved oxygen, ammonia, and fecal coliform bacteria are commonly violated in the Sandusky River below Bucyrus. Violations for phenols, foaming agents (MBAS), oil and grease, and mercury have also been recorded. The major problem appears to be combined sewer overflows.

Figure 2 Problem Areas of the Sandusky River Basin


Municipal Sewage Treatment Plants
○ Over 1 MGD
● 0.1 to 1 MGD
Green Creek
FREMONT
Muskellunge Creek
Wolf Creek
East Branch Wolf Creek
GREEN SPRINGS
TIFFIN
Honey Creek
ATTICA
BLOOMVILLE
Spring Run
Sycamore Creek
CAREY
Broken Sword Creek
Tymochtee Creek
UPPER SANDUSKY
BUCYRUS
Paramour Creek
CRESTLINE
SANDUSKY RIVER BASIN
(Problem Areas Indicated by Cross Marks)
N
Scale in Miles
0 2 4 6 8 10

A study of the combined sewer overflow problem in Bucyrus was conducted for the Federal Water Quality Administration in 1969. The study indicated that any 20-minute rainfall greater than 0.05 inches will produce an overflow of waste water into the Sandusky River. A rainfall of this intensity and duration or greater will occur on the average of once every five days.

Several fish kills in the Sandusky River at and below Bucyrus have been reported during periods of low flow. These kills generally occur when rainfall flushes the Bucyrus sewer system into the Sandusky River, but is not of enough intensity or duration to provide adequate stream dilution.

Concentrations of dissolved oxygen in the Sandusky River from above Bucyrus to below Upper Sandusky are shown in Figure 3. The measurements were made on October 16, 1974, beginning at 7:30 a.m. with the downstream location and ending at 10:00 a.m. at the upstream location. Sunrise was approximately 7:30 a.m. Some cloud cover existed until about 9:00 a.m.; from 9:00 a.m. until 10:00 a.m. there was no cloud cover. Stream flow was moderate.

The most obvious dissolved oxygen sag is below Bucyrus. This is a result of inadequate sewage treatment facilities at Bucyrus. The low dissolved oxygen readings recorded at the upstream station above Bucyrus and at mile point 88 can probably be attributed to leaf decay since both of these stations are pool areas.

Spring Run below Carey

Water quality problems in Spring Run below Carey are a result of inadequate sewage treatment from Carey. Ammonia, foaming agents (MBAS), and fecal coliform bacteria levels violated Water Quality Standards; although no dissolved oxygen violations were recorded for measurements taken in the afternoon, it is assumed that violations probably occur at night and early morning.

The stream bed in Spring Run below Carey was covered with a heavy growth of attached algae. These algae produced a supersaturation of dissolved oxygen in the stream during sunny days; however, with the cessation of photosynethesis after sunset and the continued algal respiration through the night, the algae (in combination with the BOD of the Carey STP) undoubtedly contributed to violations of the dissolved oxygen standard during the night and early morning.

Muskellunge Creek at Fremont

Muskellunge Creek received untreated sewage from a storm sewer serving a county area on the west side of Fremont. The untreated wastes caused violations of stream standards for dissolved oxygen, ammonia, foaming agents (MBAS), and fecal coliform bacteria. This area is being connected to the Fremont STP, and this should result in a considerable improvement of the water quality in the lower portion of Muskellunge Creek.

Sandusky River below Fremont

Frequent violations of the dissolved oxygen standard in the Sandusky River below Fremont have been recorded by the U.S. Geological Survey automatic water monitor, located 0.7 mile downstream of the Fremont STP. Most of the dissolved oxygen violations occur between June and November. Between June 1, 1974 and November 7, 1974, dissolved oxygen violations (less than 4.0 ppm) were recorded on 75 out of 160 days (47%). The dissolved oxygen minimum was recorded as less than 2.0 ppm on 38 out of 160 days (24%).

The Fremont STP and Heinz Company are the only known discharges immediately upstream of the automatic water monitor. The Heinz Company discharge consists of cooling water with its process water going to the Fremont STP. The Fremont STP receives heavy BOD loadings from the Heinz Company during late summer and early fall, and from Northern Ohio Sugar from fall through early spring. When equipment failures in the Fremont STP occur, heavy BOD loads are sometimes discharged into the Sandusky River. One such equipment failure occurred in late October and early November in 1974. The resulting high BOD loadings discharged into the Sandusky River caused a severe oxygen depletion. The oxygen depletion was the apparent cause of a fish kill investigated on November 9, 1974.

Violations of dissolved oxygen have also occurred when the Fremont STP appeared to be functioning properly. The exact causes of these drops in dissolved oxygen are not known for certain. However, this portion of the Sandusky River is a lacustrine estuary of Lake Erie and it is possible that the lake effect on stream flow in this area is related to the oxygen depletion observed at the automatic water monitor.

Other Areas with Violations

On occasion, fecal coliform bacteria levels violated water quality standards at most of the sampling stations. This contamination is a result of both point sources and non-point sources of pollution.

Total mercury (Hg), total copper (Cu), and phenols occasionally violated Water Quality Standards; however, no apparent trends were detected. Although mercury and copper violations were recorded at several sampling stations, no sampling station showed violations more than once except near the mouth of Wolf Creek where two violations were recorded for mercury. The sources of these heavy metals are not known.

Concentrations of nitrate (NO_3-N) approaching and exceeding the 8 mg/l standard for public water supplies has been recorded on occasion at several stations during periods of high flow. The primary source of the nitrate is probably agricultural runoff.

In summary, it appears that the major water quality problems within the Basin are related to inadequate treatment of municipal wastes and non-point sources of pollution. Water Quality Standards most frequently violated as a result of municipal wastes are dissolved oxygen, ammonia, foaming agents (MBAS), and fecal coliform bacteria. Occasional violations are recorded for phenols and certain heavy metals. The Water Quality Standard most frequently violated as a result of non-point source pollution is fecal coliform bacteria.

CONCLUSIONS AND RECOMMENDATIONS

- Based upon the levels of fecal coliform bacteria observed during the 1974 sampling program, it appears that many areas of the Sandusky River Basin are unsuitable for primary contact at certain times.

- Most areas sampled in the Sandusky River Basin appear to have water quality capable of supporting a diverse community of warm water fish. The areas excluded from this capability are:

(1) Sandusky River for approximately 4 to 8 miles below Bucyrus,

(2) Muskellunge Creek at Fremont,

(3) Spring Run below Carey, and

(4) Paramour Creek below Crestline.

- In the areas, where water quality appears to be inadequate to support warm water fisheries, the primary causes were inadequate municipal sewage treatment and combined sewer overflows.

- Although sediment samples were not included in this study, such studies should be initiated to collect data about concentrations of certain parameters in the sediments. These studies would be especially useful in the detection of heavy metal and pesticide pollution within the basin.

- Improvements in water quality in the future will depend upon the availability of Federal funds for the construction and expansion of municipal wastewater treatment facilities. Industrial point sources of pollution should be adequately controlled by the NPDES Permit System. Although non-point source polluton was not specifically addressed in this study, it is undoubtedly a problem within the Sandusky River Basin and will continue to be one until adequate control measures are implemented.

SUMMARY OF WATER QUALITY DATA

Tables 1 and 2 summarize water quality data for flow, dissolved oxygen, biochemical oxygen demand, fecal coliform bacteria, total suspended solids, total dissolved solids, ammonia, nitrate, nitrite, total kjeldahl nitrogen, total phosphorus, foaming agents (MBAS), total hardness, total copper, and total mercury. Table 1 summarizes stations sampled on the main stem of the Sandusky River and Table 2 provides a summary of stations sampled on tributary streams.

Table 1: Sandusky River Water Quality Data.

Station Location	Parameter	Flow	D.O.[a]	BOD_5	Fecal** Coliform, MF	TSS	TDS	NH_3 as N	NO_3 as N	NO_2 as N	TKN as N	Total P	MBAS	Total Hard-ness	Total Cu	Total Hg
Period of Record	Water Quality Standard	cfs	5 mg/l	mg/l	200 #/100 ml	mg/l	1500 mg/l	1.5 mg/l	mg/l	mg/l	mg/l	mg/l	0.5 mg/l	mg/l	*** ug/l	0.5 ug/l
Sandusky River 1.4 mi.	MAX	-	11.2	8.2	2500	117	650	0.41	5.2	0.06	2	0.4	0.38	342	0	0
below Fremont STP,	MIN	-	5.4	2.9	90	10	352	0.05	0.1	0.02	1	0.0	0.08	308	0	0
M.P. 12.9	MEAN	-	89%	4.8	329	78	520	0.25	2.4	0.04	1	0.2	0.16	325	0	0
Storet No. 500840	N/V*	-	9/0	8/-	8/4	9/-	9/0	9/0	10/-	5/-	8/-	10/-	10/0	2/-	10/0	10/0
February-October 1974																
Sandusky River 0.8 mi.	MAX	-	8.2	9.8	1600	22	636	0.42	1.4	0.06	2	0.3	0.19	-	0	0
below Fremont STP,	MIN	-	6.1	7.0	500	8	396	0.12	0.3	0.03	1	0.0	0.16	-	0	0
M.P. 13.5	MEAN	-	76%	8.4	843	16	513	0.27	1.0	0.04	1	0.2	0.17	-	0	0
August-October 1974	N/V	-	2/0	2/-	3/3	3/-	3/0	3/0	3/-	3/-	3/-	3/-	3/0	-	3/0	3/0
Sandusky River above	MAX	3796	15.0	13.7	20000	207	635	0.90	7.0	0.11	3	0.4	0.30	340	0	0
Fremont @ Tindall Bridge,	MIN	41	5.1	2.4	33	< 8	346	0.04	0.0	0.00	1	0.0	0.00	208	0	0
M.P. 20.3	MEAN	713	110%	6.2	426	67	496	0.22	2.5	0.04	1	0.1	0.15	295	0	0
Storet No. 500820	N/V	12/-	11/0	11/-	9/5	11/-	11/0	12/0	12/-	7/-	11/-	12/-	12/0	4/-	12/0	12/0
February-December 1974																
Sandusky River before	MAX	-	8.2	3.9	200	92	621	0.14	5.2	-	1	0.4	0.21	-	-	-
Wolf Creek @ Gilmore	MIN	-	7.4	1.8	150	55	254	0.02	1.4	-	1	0.0	0.13	-	-	-
Bridge, M.P. 24.5	MEAN	-	88%	2.8	173	74	438	0.08	3.3	-	1	0.2	0.17	322	0	0
June 1974	N/V	-	2/0	2/-	2/0	2/-	2/0	2/0	2/-	-	2/-	2/-	2.0	1/-	1/0	1/0

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[a] Mean given as average percent saturation

*N=Number of samples taken. V=Number of samples in violation of Water Quality Standards.

**Mean for fecal coliform bacteria is the geometric mean.

***Standard based upon hardness. See Ohio Water Quality Standards EP-1-02(K,L).

Table 1: Continued, Sandusky River Water Quality Data.

Station Location	Parameter	Flow	D.O.[a]	BOD_5	Fecal** Coliform, MF	TSS	TDS	NH_3 as N	NO_3 as N	NO_2 as N	TKN as N	Total P	MBAS	Total Hard-ness	Total Cu	Total Hg
Period of Record	Water Quality Standard	cfs	5 mg/1	mg/1	200 #/100 ml	mg/1	1500 mg/1	1.5 mg/1	mg/1	mg/1	mg/1	mg/1	0.5 mg/1	mg/1	*** ug/1	0.5 mg/1
Sandusky River 2.3 mi.	MAX	-	>15.0	7.4	2000	78	656	0.58	7.8	0.11	2	0.8	0.29	260	0	1.3
below Tiffin STP @ Co.	MIN	-	6.9	2.7	80	7	338	0.00	0.0	0.01	0	0.1	0.12	212	0	0
Rd. 38,	MEAN	-	118%	4.8	297	27	486	0.24	2.0	0.05	1	0.4	0.20	236	0	0.2
M.P. 36.7	N/V*	-	7/0	7/-	6/3	8/-	8/0	8/0	8/-	5/-	7/-	8/-	8/0	2/-	7/0	7/1
June-December 1974																
Sandusky River above	MAX	1910	11.9	5.7	1200	44	696	0.42	8.1	0.10	1	0.3	0.25	404	0	1.0
Tiffin @ Co. Rd. 90,	MIN	35	6.8	0.3	8	10	362	0.00	0.0	0.00	0	0.0	0.08	218	0	0
M.P. 48.0	MEAN	397	90%	3.8	92	29	467	0.13	2.4	0.03	1	0.1	0.18	282	0	0.1
(Storet No. 500830)	N/V	9/-	8/0	8/-	8/2	8/-	8/0	9/0	9/-	7/-	7/-	9/-	9/0	4/-	9/0	9/1
January-December 1974																
Sandusky River before	MAX	89	13.4	4.5	800	57	774	0.26	6.8	0.03	1.4	0.6	0.21	422	0	0
Tymochtee Creek @	MIN	32	6.8	1.7	40	< 8	340	0.00	0.0	0.00	0.0	0.0	0.06	224	0	0
S.R. 103, M.P. 67.3	MEAN	60	90%	3.1	180	30	501	0.09	1.8	0.02	0.7	0.1	0.16	333	0	0
May-December 1974	N/V	2/-	6/0	6/-	5/2	7/-	7/0	7/0	7/-	4/-	6/-	7/-	7/0	3/-	6/0	6/0
Sandusky River 1.9 mi.	MAX	830	>15.0	9.0	3700	50	964	0.25	7.4	0.06	1.0	0.9	0.31	340	200	0
below Upper Sandusky STP	MIN	13	6.4	1.7	140	8	320	0.07	0.1	0.02	0.0	0.0	0.09	180	0	0
@ Twp. Rd. 121, M.P. 78.7	MEAN	143	95%	4.2	489	28	513	0.13	2.3	0.04	0.7	0.5	0.18	283	22	0
May-December 1974	N/V	9/-	9/0	8/-	8/5	9/-	9/0	9/0	9/-	5/-	7/-	9/-	9/0	3/-	9/1	9/0

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[a] Mean given as average percent saturation

*N=Number of samples taken. V=Number of samples in violation of Water Quality Standards.

**Mean for fecal coliform bacteria is the geometric mean.

***Standard based upon hardness. See Ohio Water Quality Standards EP-1-02(K,L).

Table 1: Continued, Sandusky River Water Quality Data.

Station Location	Parameter	Flow	D.O.[a]	BOD_5	Fecal** Coliform, MF	TSS	TDS	NH_3 as N	NO_3 as N	NO_2 as N	TKN as N	Total P	MBAS	Total Hard- ness	Total Cu	Total Hg
Period of Record	Water Quality Standard	cfs	5 mg/1	mg/1	200 #/100 ml	mg/1	1500 mg/1	1.5 mg/1	mg/1	mg/1	mg/1	mg/1	0.5 mg/1	mg/1	*** ug/1	0.5 ug/1
Sandusky River above	MAX	828	12.5	8.3	3100	95	560	0.31	7.4	0.04	1.0	0.6	0.32	-	180	0
Upper Sandusky @ High	MIN	37	6.2	1.1	50	< 8	346	0.05	0.4	0.01	0.0	0.0	0.16	-	0	0
Street, M.P. 84.1	MEAN	190	80%	3.6	343	29	430	0.12	2.7	0.02	0.6	0.3	0.23	208	30	0
August-December 1974	N/V*	6/-	6/0	6/-	6/3	6/-	6/0	6/0	6/-	5/-	6/-	6/-	6/0	1/-	6/1	6/0
Sandusky River 8.8 mi.	MAX	118	14.4	7.8	230	39	524	1.89	5.6	0.31	2.0	2.3	0.35	326	0	1.0
below Bucyrus STP @	MIN	12	6.2	2.4	60	10	373	0.01	1.9	0.04	1.0	0.0	0.17	222	0	0
Caldwell Rd.,	MEAN	34	97%	4.9	68	24	440	0.60	3.3	0.14	1.4	1.3	0.27	274	0	0.2
M.P. 102.8	N/V	5/-	5/0	4/-	3/1	4/-	4/0	5/1	5/-	3/-	33/-	5/-	5/0	2/-	5/0	5/1
May-October 1974																
Sandusky River 2.8 mi.	MAX	14	7.8	6.5	470	22	518	4.69	2.4	0.47	5.5	3.2	0.40	-	0	1.2
below Bucyrus STP @	MIN	12	2.7	4.8	17	8	358	0.52	1.7	0.01	1.0	0.5	0.21	-	0	0
Denzer Rd., M.P. 108.8	MEAN	13	52%	5.4	108	15	441	2.34	2.2	0.27	2.9	2.0	0.34	-	0	0.3
August-October 1974	N/V	4/-	4/2	4/-	3/1	2/-	3/0	4/3	4/-	4/-	4/-	4/-	4/0	-	4/0	4/1
Sandusky River 0.6 mi.	MAX	310	12.3	20.0	>15000	106	498	3.90	7.4	0.25	6.0	2.6	0.53	318	0	0
below Bucyrus STP @	MIN	11	4.6	2.5	66	6	266	0.16	0.0	0.04	0.7	0.0	0.16	214	0	0
Kestetter Rd.,	MEAN	75	70%	7.4	1073	30	401	1.63	2.7	0.14	2.4	1.0	0.33	257	0	0
M.P. 111.0	N/V	9/-	9/2	8/-	5/2	8/-	8/0	9/4	9/-	6/-	8/-	9/-	9/1	3/-	9/0	9/0
May-December 1974																

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[a] Mean given as average percent saturation

*N=Number of samples taken. V=Number of samples in violation of Water Quality Standards.

**Mean for fecal coliform bacteria is the geometric mean.

***Standard based upon hardness. See Ohio Water Quality Standards EP-1-02(K,L).

Table 1: Continued, Sandusky River Water Quality Data.

Station Location	Parameter	Flow	D.O.[a]	BOD$_5$	Fecal** Coliform, MF	TSS	TDS	NH$_3$ as N	NO$_3$ as N	NO$_2$ as N	TKN as N	Total P	MBAS	Total Hard-ness	Total Cu	Total Hg
Period of Record	Water Quality Standard	cfs	5 mg/1	mg/1	200 #/100 ml	mg/1	1500 mg/1	1.5 mg/1	mg/1	mg/1	mg/1	mg/1	0.5 mg/1	mg/1	*** ug/1	0.5 ug/1
Sandusky River in	MAX	306	10.0	16.9	>15000	110	436	0.15	3.1	0.05	1.0	0.5	0.30	-	0	0
Bucyrus 0.6 mi. above	MIN	6.2	6.2	2.3	55	<8	314	0.04	0.0	0.01	0.0	0.0	0.11	-	0	0
Bucyrus STP @ Aumiller	MEAN	69	80%	6.9	1631	31	374	0.09	1.2	0.03	0.4	0.2	0.21	-	0	0
Park, M.P. 112.2	N/V*	5/-	5/0	5/-	4/3	4/-	4/0	5/0	5/-	5/-	5/-	5/-	5/0	-	5/0	5/0
August-October 1974																
Sandusky River above	MAX	12	12.3	7.2	5400	38	484	0.23	3.5	0.03	1.0	0.6	0.23	-	0	0
Bucyrus @ Beechgrove Rd.,	MIN	6	4.0	1.2	33	8	286	0.00	0.0	0.01	0.0	0.0	0.09	-	0	0
M.P. 116.0	MEAN	10	70%	4.4	182	16	385	0.10	1.3	0.02	0.6	0.3	0.14	208	0	0
August-December 1974	N/V	4/-	5/1	5/-	4/1	4/-	4/0	5/0	5/-	5/-	5/-	5/-	5/0	1/-	5/0	5/0
Sandusky River @	MAX	19	11.4	3.9	1470	10	536	1.07	2.3	0.14	2.4	1.8	0.26	350	0	1.0
Leesville Rd., M.P. 127.7	MIN	3.9	7.7	2.4	110	4	408	0.24	1.0	0.06	1.0	0.5	0.13	260	0	0
May-October 1974	MEAN	11	89%	3.4	562	7	472	0.71	1.8	0.10	1.5	1.1	0.18	305	0	0.3
	N/V	2/-	4/0	4/-	3/2	2/-	2/0	4/0	4/-	2/-	3/-	4/-	4/0	2/-	3/0	3/1

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[a] Mean given as average percent saturation

*N=Number of samples taken. V=Number of samples in violation of Water Quality Standards.

**Mean for fecal coliform bacteria is the geometric mean.

***Standard based upon hardness. See Ohio Water Quality Standards EP-1-02(K,L).

Table 2: Sandusky River Tributaries Water Quality Data.

Station Location	Parameter	Flow	D.O.[a]	BOD_5	Fecal** Coliform, MF	TSS	TDS	NH_3 as N	NO_3 as N	NO_2 as N	TKN as N	Total P	MBAS	Total Hard-ness	Total Cu	Total Hg
Period of Record	Water Quality Standard	cfs	5 mg/1	mg/1	200 #/100 ml	mg/1	1500 mg/1	1.5 mg/1	mg/1	mg/1	mg/1	mg/1	0.5 mg/1	mg/1	*** ug/1	0.5 ug/1
Broken Sword Creek @	MAX	29	11.6	8.4	260	180	477	0.13	2.7	0.00	2.0	0.5	0.20	358	100	0
Wyandot Co. Rd. 62,	MIN	9.8	6.6	1.1	80	23	303	0.05	0.0	0.00	0.0	0.0	0.05	312	0	0
M.P. 0.7	MEAN	19	86%	3.8	153	88	415	0.08	0.9	0.00	1.0	0.2	0.11	335	25	0
May-October 1974	N/V*	2/-	5/0	5/-	4/2	3/-	3/0	5/0	5/-	3/-	4/-	5/-	5/0	2/-	4/1	4/0
Honey Creek @ Wyandot	MAX	-	8.1	6.0	2800	40	678	0.24	1.4	0.01	1.0	0.2	0.18	-	0	0
Co. Rd. 19, M.P. 1.1	MIN	-	6.4	1.2	120	<8	499	0.00	0.0	0.00	0.0	0.0	0.06	-	0	0
June-October 1974	MEAN	-	69%	2.9	394	21	581	0.09	0.5	0.00	0.2	0.1	0.08	350	0	0
	N/V	-	6/0	5/-	5/4	5/-	5/0	5/0	5/-	4/-	5/-	5/-	5/0	1/-	4/0	3/0
Muskellunge Creek @	MAX	-	7.0	17.0	8700	27	674	1.45	0.7	0.07	1.9	1.2	0.27	-	0	1.1
Fangboner Road,	MIN	-	0.4	2.0	350	<8	593	0.20	0.0	0.01	0.0	0.3	0.21	-	0	0
M.P. 1.1	MEAN	-	28%	6.4	1692	19	630	0.83	0.4	0.04	1.1	0.8	0.24	-	0	0.2
September-November 1974	N/V	-	5/4	5/-	5/5	5/-	5/0	4/0	4/-	4/-	4/-	4/-	4/0	-	5/0	5/1
Muskellunge Creek	MAX	-	8.0	45.0	>15000	15	671	5.10	0.3	0.04	5.8	2.8	0.64	-	-	-
immediately downstream	MIN	-	0.2	11.2	>15000	<8	555	1.32	0.0	0.01	1.8	0.7	0.26	-	-	-
from West State Street,	MEAN	-	26%	22.9	>15000	10	618	3.21	0.2	0.03	3.8	1.8	0.45	-	-	-
M.P. 4.3	N/V	-	4/3	4/-	4/4	4/-	4/0	2/1	2/-	2/-	2/-	2/-	2/1	-	-	-
September-November 1974																

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[a] Mean given as average percent saturation

*N=Number of samples taken. V=Number of samples in violation of Water Quality Standards.

**Mean for fecal coliform bacteria is the geometric mean.

***Standard based upon hardness. See Ohio Water Quality Standards EP-1-02(K,L).

Table 2: Continued, Sandusky River Tributaries Water Quality Data.

Station Location	Parameter	Flow	D.O.[a]	BOD_5	Fecal** Coliform, MF	TSS	TDS	NH_3 as N	NO_3 as N	NO_2 as N	TKN as N	Total P	MBAS	Total Hard-ness	Total Cu	Total Hg
Period of Record	Water Quality Standard	cfs	5 mg/1	mg/1	200 #/100 ml	mg/1	1500 mg/1	1.5 mg/1	mg/1	mg/1	mg/1	mg/1	0.5 mg/1	mg/1	*** ug/1	0.5 ug/1
Muskellunge Creek @	MAX	-	10.2	18.6	850	45	639	0.33	0.2	0.01	1.0	0.3	0.33	-	0	0
Muskellunge Creek Rd.,	MIN	-	5.7	4.1	80	8	474	0.12	0.0	0.00	0.0	0.0	0.10	-	0	0
M.P. 4.5	MEAN	-	72%	9.4	209	28	560	0.23	0.1	0.01	0.6	0.2	0.18	-	0	0
September-November 1974	N/V*	-	5/0	5/-	5/2	5/-	5/0	4/0	4/-	4/-	4/-	4/-	4/0	-	3/0	3/0
Paramour Creek 1.0 mi.	MAX	-	12.2	14.4	>15000	8	588	7.19	2.4	0.07	9.0	3.6	0.92	-	0	0
below Crestline STP @	MIN	-	0.2	0.9	>15000	<8	332	0.28	0.2	0.01	1.1	0.6	0.11	-	0	0
Nazor Rd., M.P. 1.5	MEAN	2.8	25%	5.2	>15000	<8	499	4.88	0.7	0.04	5.8	2.4	0.67	110	0	0
June-December 1974	N/V	1/-	5/4	5/-	5/5	3/-	3/0	5/4	5/-	4/-	5/-	5/-	5/4	1/-	4/0	4/0
Paramour Creek above	MAX	-	8.2	3.9	500	12	522	0.04	1.9	0.01	1.0	0.5	0.15	-	0	0
Crestline STP @	MIN	-	7.0	0.6	120	2	462	0.02	0.1	0.00	0.0	0.0	0.10	-	0	0
Krichbaum Rd., M.P. 2.9	MEAN	0.8	73%	1.6	262	7	487	0.03	1.0	0.01	0.7	0.1	0.12	356	0	0
June-December 1974	N/V	1/-	4/0	4/-	4/3	3/-	3/0	4/0	4/-	3/-	4/-	4/-	4/0	1/-	2/0	2/0
South Branch Paramour	MAX	2.8	8.9	2.4	-	23	508	0.17	1.3	-	-	0.4	0.13	380	-	-
Creek @ Horning Rd.,	MIN	0.6	6.0	0.8	-	2	381	0.16	1.0	-	-	0.3	0.09	236	-	-
M.P. 0.7	MEAN	1.7	72%	1.6	100	12	444	0.16	1.2	-	1	0.4	0.11	308	0	0
May-June 1974	N/V	2/-	2/0	2/-	1/0	2/-	2/0	2/0	2/-	-	1/-	2/-	2/0	2/-	1/0	1/0

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[a] Mean given as average percent saturation.

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** Mean for fecal coliform bacteria is the geometric mean.

***Standard based upon hardness. See Ohio Water Quality Standards EP-1-02(K,L).

Table 2: Continued, Sandusky River Tributaries Water Quality Data.

Station Location Period of Record	Parameter Water Quality Standard	Flow cfs	D.O.[a] 5 mg/1	BOD_5 mg/1	Fecal** Coliform MF 200 #/100 ml	TSS mg/1	TDS 1500 mg/1	NH_3 as N 1.5 mg/1	NO_3 as N mg/1	NO_2 as N mg/1	TKN as N mg/1	Total P mg/1	MBAS 0.5 mg/1	Total Hard- ness mg/1	Total Cu *** ug/1	Total Hg 0.5 ug/1
Sycamore Creek @	MAX	-	9.2	5.7	1500	16	718	0.09	0.6	0.01	1.0	0.0	0.16	-	0	0
Wyandot Co. Rd. 37,	MIN	-	8.7	1.2	130	<8	578	0.02	0.2	0.00	0.0	0.0	0.11	-	0	0
M.P. 0.4	MEAN	-	86%	3.4	400	12	648	0.07	0.3	0.01	0.4	0.0	0.13	-	0	0
September-October 1974	N/V*	-	3/0	3/-	3/2	2/-	2/0	3/0	3/-	3/-	3/-	3/-	3/0	-	2/0	3/0
Tymochtee Creek @ S.R.	MAX	32	12.6	3.6	450	56	979	0.09	13.5	0.19	1.4	1.0	0.32	516	0	0
53, M.P. 0.3	MIN	9.7	5.7	0.5	150	<8	538	0.01	1.5	0.02	0.0	0.0	0.00	250	0	0
May-December 1974	MEAN	20	85%	2.5	228	28	738	0.05	3.9	0.08	0.5	0.5	0.18	405	0	0
	N/V	3/-	7/0	7/-	6/3	8/-	8/0	8/0	8/-	4/-	7/-	8/-	8/0	3/-	8/0	8/0
Spring Run 2.8 mi. below	MAX	6.8	13.6	-	-	22	774	1.73	3.3	-	2.0	1.8	0.90	498	-	-
Carey STP @ Mott Rd.,	MIN	5.8	5.8	-	-	12	744	1.71	3.0	-	2.0	1.7	0.18	446	-	-
M.P. 1.5	MEAN	6.3	94%	3.3	720	17	759	1.72	3.2	-	2.0	1.8	0.54	472	0	0
May-June 1974	N/V	2/-	2/0	1/-	1/1	2/-	2/0	2/2	2/-	-	2/-	2/-	2/1	2/-	1/0	1/0
Tymochtee Creek @	MAX	287	13.1	8.4	1220	63	898	0.28	13.7	0.10	1.4	0.0	0.27	540	0	0
S.R. 199, M.P. 8.1	MIN	0.1	5.6	2.4	20	<8	424	0.00	0.1	0.01	0.0	0.0	0.09	248	0	0
April-December 1974	MEAN	42	97%	4.6	80	31	669	0.12	2.1	0.05	0.8	0.0	0.15	393	0	0
	N/V	8/-	7/0	7/-	4/1	8/-	8/0	8/0	8/-	4/-	7/-	8/-	8/0	3/-	6/0	6/0

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[a] Mean given as average percent saturation.

*N=Number of samples taken. V=Number of samples in violation of Water Quality Standards.

**Mean for fecal coliform bacteria is the geometric mean.

***Standard based upon hardness. See Ohio Water Quality Standards EP-1-02(K,L).

Table 2: Continued, Sandusky River Tributaries Water Quality Data.

Station Location	Parameter	Flow	D.O.[a]	BOD_5	Fecal** Coliform, MF	TSS	TDS	NH_3 as N	NO_3 as N	NO_2 as N	TKN as N	Total P	MBAS	Total Hard-ness	Total Cu	Total Hg
Period of Record	Water Quality Standard	cfs	5 mg/1	mg/1	200 #/100 ml	mg/1	1500 mg/1	1.5 mg/1	mg/1	mg/1	mg/1	mg/1	0.5 mg/1	mg/1	*** ug/1	0.5 ug/1
Wolf Creek @ S.R. 53,	MAX	-	13.2	5.6	460	46	606	1.33	4.5	0.03	2.4	2.2	0.40	-	0	1.7
M.P. 0.1	MIN	-	6.9	0.9	17	<8	400	0.00	0.0	0.00	0.0	0.0	0.09	-	0	0
June-November 1974	MEAN	24	101%	3.2	79	15	545	0.24	1.7	0.01	0.8	0.4	0.18	368	0	0.4
	N/V*	1/-	7/0	7/-	7/1	7/-	7/0	6/0	6/-	4/-	6/-	6/-	6/0	1/-	6/0	6/2
East Branch Wolf Creek	MAX	-	10.9	6.2	80	9	644	0.14	0.3	0.01	1.0	0.1	0.38	-	0	1.8
@ Gilmore Bridge,	MIN	-	7.8	2.1	17	<8	528	0.12	0.0	0.00	0.0	0.0	0.06	-	0	0
M.P. 0.9	MEAN	-	90%	4.3	45	<8	599	0.13	0.1	0.00	0.7	0.0	0.16	-	0	0.4
September-November 1974	N/V	-	5/0	5/-	5/0	5/-	5/0	5/0	5/-	5/-	5/-	5/-	5/0	-	5/0	5/-

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**Mean for fecal coliform bacteria is the geometric mean.

***Standard based upon hardness. See Ohio Water Quality Standards EP-1-02(K,L).

Table 1 stations are arranged in order by river mile point (M.P.) beginning with the stations nearest the mouth of the Sandusky River and ending with the stations farthest upstream. Table 2 stations are arranged in alphabetical order for the major tributaries. When a tributary has more than one sampling location, the stations are listed in river mile point order beginning with the stations nearest the mouth. The river mile point is the distance in miles from the sampling location to the mouth of the Sandusky River, or in the case of tributary stations, the distance to the mouth of the tributary.

It should be noted that the lower limit for reliable measurement of copper was 30 ug/l and .05 ug/l for mercury. Analytical results that were less than these limits were reported as 0. The water quality standard for mercury is 0.5 ug/l. Although the standard varies for copper (depending on hardness),if hardness is less than 240 mg/l, then the water quality standard for copper is less than the lower detectable limit (30 ug/l).

Values reported as 'less than' (<) or 'greater than' (>) were included when calculating means. For example, if a value of > 15000 is given, the value 15000 was used to calculate the mean.

In addition to the parameters summarized in Tables 1 and 2, a number of other water quality parameters were measured at most of the sampling stations. These parameters were: pH, temperature, chloride, conductivity, dissolved fluoride, fecal streptococcus bacteria, phenols, cyanide, oil/grease, turbidity, total alkalinity, total arsenic, total barium, total cadium, total chromium, hexavalent chromium, total iron, total lead, total manganese, total selenium, total silver, and total zinc. These parameters are summarized in the Sandusky River Basin 303(e) and 305(b) Reports.

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ABSTRACT

EFFECTS OF ADVANCED WASTE TREATMENT AND FLOW AUGMENTATION ON WATER QUALITY DURING LOW STREAM FLOWS

D.B. BAKER AND J.W. KRAMER

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During periods of low stream flow, especially in summer and fall, algal growth often reaches nuisance levels as judged by aesthetic considerations and data from oxygen monitors. As stream flow decreases, nutrient concentrations increase in stream stretches below sewage treatment plants, the travel-time increases (i.e. the river becomes lake like), and turbidity associated with inorganic sediment decreases. These, and possibly other factors, provide conditions that support the algal growth. Nutrient removal at sewage plants and flow augmentation from upground reservoirs may be effective in reducing this problem.

Comparison of diurnal oxygen fluctuations and stream flow at three continuous water quality monitors in the basin illustrate the effectiveness of runoff events in diminishing oxygen fluctuations. During the drought periods of July, 1974, flow augmentation releases from Killdeer Reservoir were sufficient to reduce oxygen fluctuations at the Tymochtee station. This effect accompanied the arrival of the flood front and preceded by three days the actual arrival of water from the reservoir.

During June-Sept., 1974, nutrient and chlorophyll concentrations were measured in the basin. The study area bracketed four point source inputs. Phosphorous concentrations increased sharply below each treatment plant but both concentration and flux decreased with passage downstream. At a given station no obvious correlation between phosphorous and chlorphyll was apparent. Physical characteristics of the stream, such as low-head dams and sections with high fall rates, did influence chlorophyll levels.

Two of the municipalities have instituted nutrient removal programs and the effects of these on nutrient and chlorophyll levels along the stream will be investigated in the summers of 1975 and 1976.

EFFECTS OF ADVANCED WASTE TREATMENT AND FLOW AUGMENTATION ON WATER QUALITY DURING LOW STREAM FLOWS

DAVID B. BAKER AND JACK W. KRAMER
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INTRODUCTION

Often the daily minimum concentration of dissolved oxygen in streams drops as streamflow decreases. This is particularly true during the late summer and fall periods when water temperatures are high and the solubility of oxygen is low. When designing a sewage treatment plant, one goal is to be able to produce an effluent which will not result in water quality violations, as long as the streamflow exceeds a certain value. In Ohio, water quality standards are applicable whenever the flows exceed the annual minimum seven-day average flow that has a recurrence frequency of once in ten years (Ohio Environmental Protection Agency, 1975). Determining the maximum organic loading allowable for a sewage treatment plant involves determining the assimilative capacity of the stream during periods of late summer, low-flow conditions (Thomann, 1972; Cahill et al, 1975).

As mentioned in the introductory paper in this symposium, most of the oxygen violations in the Sandusky River (i.e., instances when the dissolved oxygen [D.O.] drops below 4.0 mg/l) are associated with diurnal oxygen fluctuations. This indicates that the metabolism of photosynthetic plants, rather than heterotrophic bacteria, is a major factor in determining the oxygen concentrations in the stream. Since the Sandusky River essentially lacks rooted aquatic plants, attached algae and/or phytoplankton are apparently responsible for the diurnal oxygen variations.

When constant loading of organic matter from a sewage treatment plant is the cause of low D.O. values, the relationship between D.O. and streamflow can be explained, in part, in terms of a decreasing dilution of the organic wastes as the streamflow decreases. When algae are the cause of the low D.O. values, similar D.O./streamflow relationships occur as for organic loading, but the explanation is less clear-cut. Do algal concentrations increase as streamflow decreases, and if so, why? As stream flow decreases, do the physical changes associated with velocity and surface/volume ratios change in such a way as to decrease reaeration rates? Does the water mainly provide a "buffer" for a relatively stable benthic algal population so that as streamflow decreases, "buffer" capacity decreases? Our research is primarily directed toward the first of these three possibilities.

Three reasons why algal populations might increase as streamflow decreases would be that: (1) phosphorus concentrations increase, (2) the sediment concentrations decrease, thereby increasing the penetration of light, and (3) the time for algal growth increases greatly because of streamflow/time-of-travel relationships.

We have ample evidence to indicate that all of these effects occur within the Sandusky Basin. Figure 1a shows the relationship between the concentrations of total phosphorus and streamflow at a collection station a short distance downstream from a sewage treatment plant. As would be expected, when the streamflow decreases in the low flow range, the concentration of phosphorus increases, since there is less stream water to dilute the rather constant phosphorus inputs from the sewage treatment plant.

The plot in figure 1a also shows that the total phosphorus concentration increases as flow increases in the high flow ranges. This is a consequence of the increased sediment concentrations present during surface runoff events. Much phosphorus is adsorbed to the sediment. Figure 1b shows the

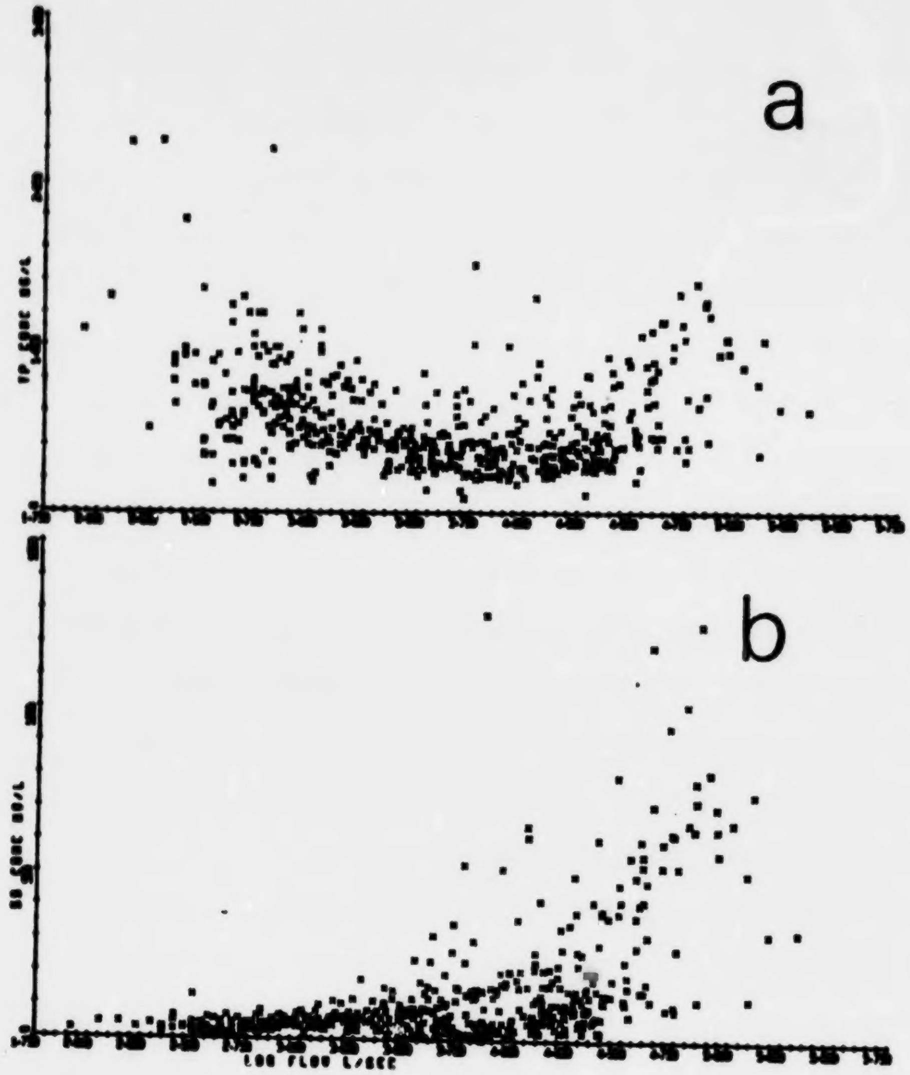

Figure 1. Patterns of concentrations of total phosphorous (A) and suspended solids (B) as a function of streamflow at the stream gage below Upper Sandusky, Ohio. Flows are expressed as the log (base 10) of the stream flow in liters per second. Includes data collected between June 1969 and November 1974. Unpublished data, Heidelberg College River Studies Laboratory.

relationship between suspended sediments and flow at the same station. The concentrations of suspended sediments are lowest during periods of low flows. This results in increasing transparency of the water as flow decreases.

Figure 2 presents some data showing the relationship between time-of-travel in the stream and streamflow, for several distances downstream from the Bucyrus sewage treatment plant. Normally these kinds of data are presented on log-log plots. The linear plots of figure 2 emphasize the large increases in time-of-travel which occur as stream flow decreases, particularly in the low flow ranges. The curves depict the river becoming "lake-like" as the flow decreases.

If it is deemed important to attempt to control water-quality effects associated with algae in rivers, an understanding of the interrelationships among streamflow, algal growth and diurnal oxygen fluctuations would be useful. In the Sandusky River, as well as other streams in Northwestern Ohio, attempts to prevent the development of nuisance levels of algae could include: (1) providing phosphorus removal at domestic sewage treatment plants and (2) providing increased streamflow during periods of low streamflow, using water stored in off-stream, upground reservoirs. Several of these reservoirs have been constructed as part of the Northwestern Ohio Development Plan (Ohio Department of Natural Resources, 1967).

Our approach in studying management options related to controlling algae in the Sandusky River Basin is direct. We will be measuring chlorophyll and nutrient concentrations in the river prior to and following removal of phosphorus at domestic sewage treatment plants in the basin. Also, during periods of low streamflow water will be released from the Killdeer Reservoir in the Tymochtee Basin. These releases can significantly

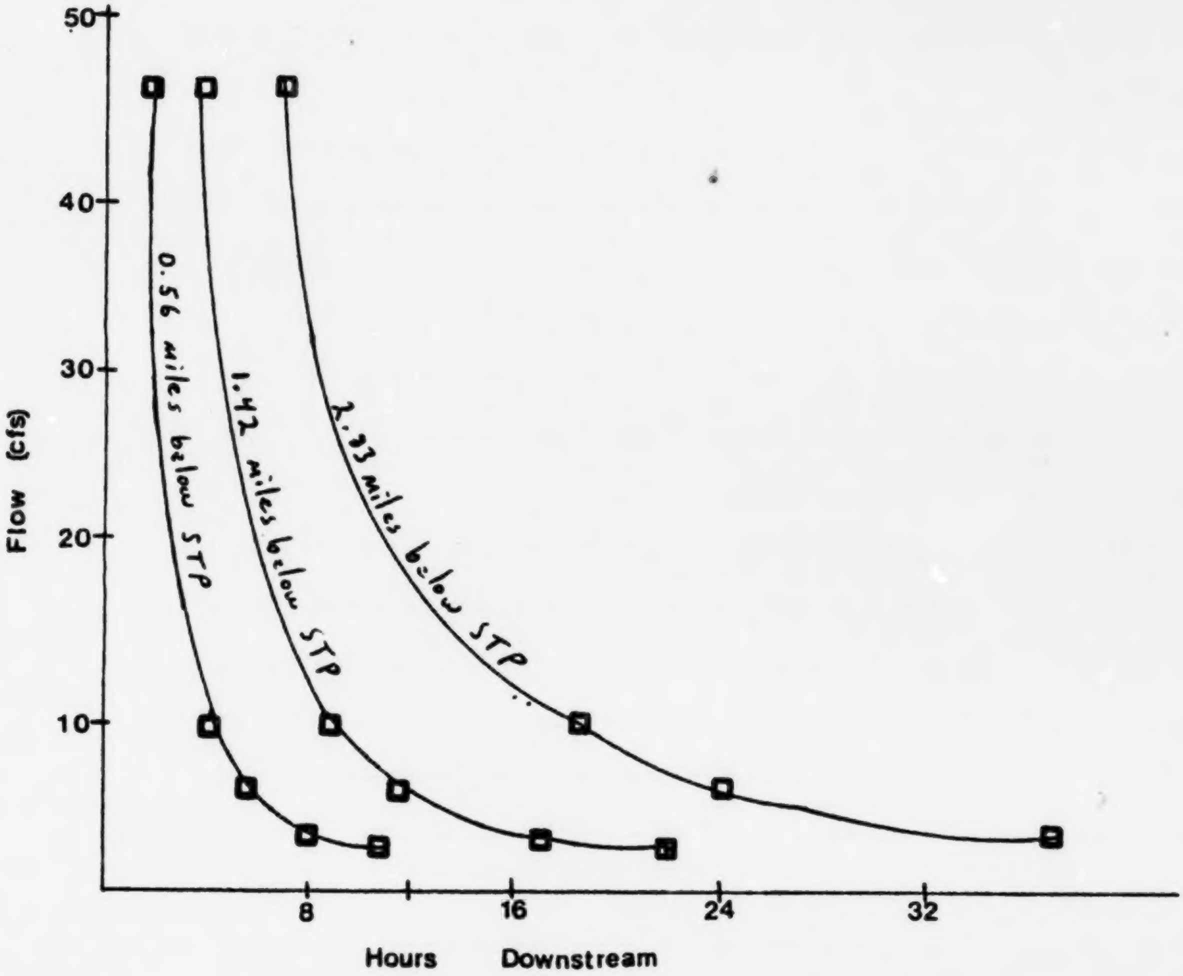

Figure 2 Time-of-travel of water in the Sandusky River in the river stretch downstream 0.56, 1.42, and 2.83 miles from the sewage treatment plant at Bucyrus, Ohio. At this station flows of 3.8 cfs are exceeded 80% of the time. Unpublished data, Heidelberg College River Studies Laboratory.

augment flows both in Tymochtee Creek and in the Sandusky below its confluence with Tymochtee Creek. Both of the above "manipulations" of the stream system have been made possible through cooperative research-planning with the Ohio Environmental Protection Agency and the Ohio Department of Natural Resources.

This report contains the preliminary findings of the first year of a three year study. During the first year, none of the municipalities in the basin utilized phosphorus removal procedures at their sewage treatment plants. For the second and third years of study, phosphorus removal procedures will be in effect.

Hynes (1970) has reviewed many of the factors which can affect the growth of phytoplankton in rivers. The difficulties of including algal growth and metabolism in oxygen models for rivers are noted by Thomann (1972).

METHODS

Three samples per week were collected at each of 29 collection stations located along the Sandusky River or its tributaries. All collections were made from bridges using buckets lowered by rope. Field measurements included dissolved oxygen and temperature. All samples were delivered to the laboratory within 6 hours of sample collection. Upon arrival, the samples were immediately divided into four portions, one for *in vivo* chlorophyll analysis, one for filtration through a glass fiber filter for subsequent acetone extraction and chlorophyll determination, one for filtration through 0.45 μ membrane filters for analysis of dissolved nutrients in the filtrate, and one for additional analyses, including total phosphorus, suspended solids and conductivity. The study extended from June 3 to October 9, 1974.

Both total phosphorus and soluble orthophosphate were measured using the single reagent automated method, as described in Methods for Analysis of Water and Wastes (U.S. Environmental Protection Agency, 1971). Suspended solids and conductivities were also measured according to procedures described in the above manual. See Baker and Kramer (1976) for further descriptions of the analytical procedures used in our laboratory for nutrient analyses.

In vivo chlorophyll was measured with a Turner Model 111 fluorometer outfitted with a high sensitivity door, a R-136 photomultiplier and a blue 4 watt GE F4T5-B lamp. The primary filters were a Kodak 47 B and a 2A in combination and the secondary filter was a Corning CS-2-64. The *in vivo* measurements represent the fluorometer readouts as related to the most sensitive scale on the fluorometer. The data may be interpreted as a rough estimate on a relative scale of the algal standing crop.

For acetone-extractable chlorophyll, 50 ml of the sample was filtered through a RA 934 AH glass fiber filter. Two drops of a 2% slurry of magnesium carbonate were added to the sample prior to filtration. The filter was stored in a freezer for a period ranging from two days to two weeks, after which the filter was ground in 90% acetone, the slurry being adjusted to a total volume of 15 ml. After 24 hours of extraction in a refrigerator, the supernatant acetone was decanted and its fluorescence determined both before and after the addition of acid. A GE F4T4-BL lamp was used in the fluorometer and the secondary filter was changed to a Kodak 25 + 23A filter combination.

According to the procedures described by Holm-Hanson, et. al (1965), the addition of acid allows correction for phaeophytin. The fluorometric determination of chlorophyll a was calibrated using the trichromatic method as described by Creitz and Richards (1955). The chlorophyll a concentrations are expressed as mg/l of chlorophyll a in the original water sample.

RESULTS AND DISCUSSION

Diurnal Oxygen Fluctuations

Figure 3 shows the extent of diurnal fluctuations in D.O. at three continuous water quality monitors in the study area. The plots show the range of values from maximum to minimum for each day from July 1, 1974 through September 15, 1974. The mean daily streamflows at each of the monitors are also shown.

The largest diurnal fluctuations occurred at the monitor located 2 miles downstream from Upper Sandusky (Figure 3a). At this station the D.O. dropped below 4.0 mg/l on 20 days during this period.

At St. John's Bridge, about 29 miles downstream from the monitor at Upper Sandusky, the D.O. dropped below 4.0 mg/l on 47 days (Figure 3b), according to the monitor data. The amplitude of the diurnal oxygen fluctuation at this station were much smaller than at Upper Sandusky. A possible explanation is that the intake to the monitor at St. John's Bridge is located immediately downstream from a low-headed dam. Water passing over the dam splashes on bedrock before reaching the intake, especially during the periods of low flow. The resulting aeration could reduce the amplitude of the diurnal fluctuations that may characterize the stream section above the dam. Also, measurements of D.O. in 17 grab samples collected at the monitor site gave D.O. values that averaged 2.6 mg/l higher than the average of the daily maximum D.O. reported from the monitor for the same days. The grab samples were all collected before noon so they probably did not reflect the D.O. maximum for the days. The sampling pump for the monitor pulls the water about 20 feet to the probe box. Possibly, dissolved gases are stripped from the water by the pumping system. This problem was not apparent at the other monitors.

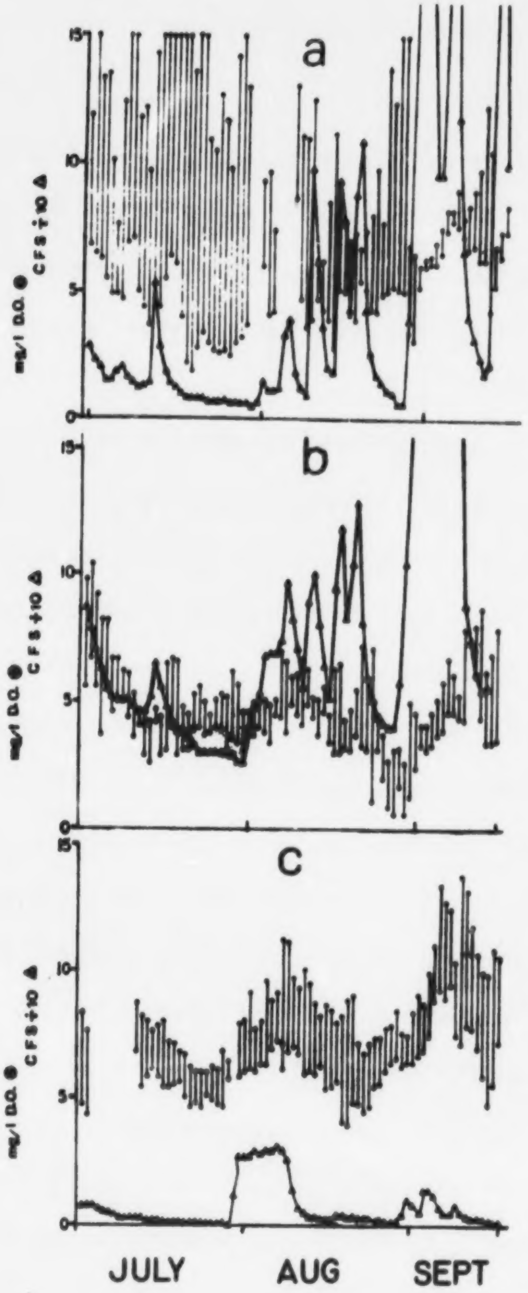

Figure 3. Diurnal oxygen fluctuations and stream flows at three automatic water-quality monitors in the Sandusky Basin during the period from July 1 through September 15, 1974. Figure 3a, Upper Sandusky; Figure 3b, Mexico; Figure 3c, Tymochtee Creek. The maximum dissolved oxygen that the monitors record is 15 mg/l. Data are taken from Water Quality Records for Ohio, Parts I and II (U.S. Department of Interior, 1974).

At the monitor on Tymochtee Creek near Crawford (figure 3c) the D.O. dropped below 4.0 mg/l only once during the study period. It is possible that flow augmentation prevented oxygen violations at this station (see next section), since in previous years more violations have been noted. The diurnal fluctuations of D.O. in Tymochtee Creek are small in comparison to the Upper Sandusky site. Both phosphorus and chlorophyll concentrations are much lower at this location than at sites along the mainstream (Table 1). The watershed above this monitor is principally agricultural.

Flow Augmentation

When the stream flow increases at a water quality monitor, the D.O. tends to increase. Several examples of this can be seen in the graphs in figure 3. Some particularly clear cut examples can be found in earlier Water Quality Records for Ohio (U.S. Department of Interior, 1974 and earlier years) for these same stations. Although these data show the effects of natural runoff events, similar results may accompany flow augmentation.

The results of a flow augmentation "experiment" on Tymochtee Creek are shown in figure 4. On July 24, at 1200 hours a release of 30 ft^3/s was initiated at Killdeer Reservoir, which is located 31 miles upstream from the water quality monitor at Crawford. The stream flow at Crawford was less than 1 ft^3/s. On July 28 the flow abruptly increased to 25 ft^3/s. At 800 hours the flow was still less than 1 ft^3/s and at 2200 hours it was just over 25 ft^3/s. It had taken approximately 96 hours for the flood front to travel the 31 miles to the gage station. Once the flood front reached the station the flow remained relatively constant for the next nine days.

Figure 4 also shows the stream conductivities as measured at the

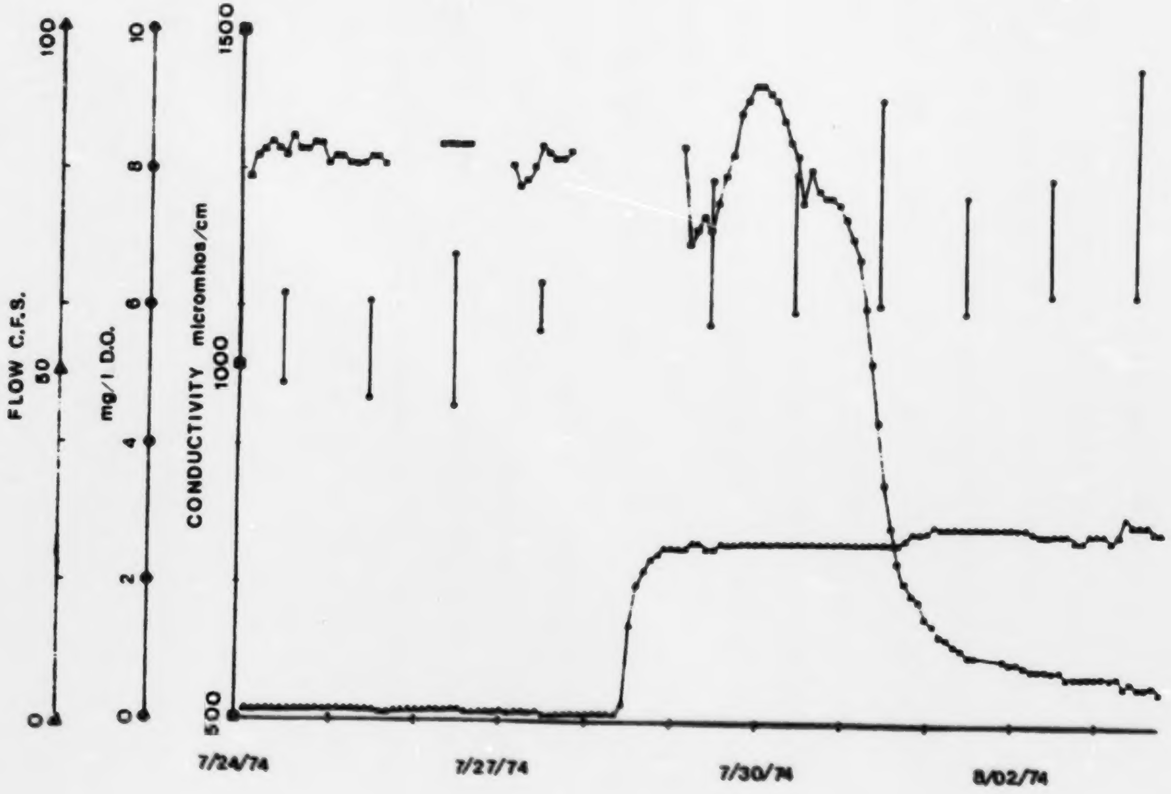

Figure 4. Bihourly readings of streamflow and conductivity at the Crawford water quality monitor on Tymochtee Creek. Diurnal oxygen concentrations are also indicated. Data cover the period before and after the arrival of flow augmentation water released from Killdeer Reservoir. Bihourly dta was supplied by the U.S. Geological Survey, Columbus, Ohio.

water quality monitor. Initially the conductivity of the stream water exceeded 1,300 μmhos. Since the conductivity of the reservoir water was only about 560 μmhos, the conductivity provided a good marker to indicate the actual arrival of water that had been stored in the reservoir. As can be seen in figure 4, significant drops in conductivity did not occur until July 31. At 1400 hours, July 30, the conductivity was still at 1,300 μmhos and not until 1800 hours, August 1, did the conductivity drop below 600 μmhos. A conductivity of 950 μmhos, which would represent about 50% stream water and 50% reservoir water, occur at 1000 hours on July 31. In traveling 31 miles the augmentation water lagged behind the flood front by about 70 hours and required a total of 166 hours to reach the monitor.

Prior to the arrival of the flow augmentation water, the minimum D.O. value had been decreasing, except for the day immediately preceeding the arrival of the flood front. Unfortunately the monitor was not in operation the day the flood front arrived. The slight dip in conductivity on July 27 could indicate a light shower which could have affected the D.O. It is clear that the daily minimum D.O. values were higher after the flood front reached the station. The arrival of the water originating from the reservoir had little additional affect on the minimum D.O. values, at least through August 3. The daily maximum and minimum temperature did not change significantly during the entire period shown on the graph in figure 4. The stage rose 0.4 ft as a result of the flow augmentation.

CONCENTRATION PROFILES FOR PHOSPHORUS AND CHLOROPHYLL

Table 1 contains a summary of the results of our summer sampling program. For each of four parameters (ortho phosphorus, total phosphorus, *in vivo* chlorophyll and acetone chlorophyll) the total number of measurements (N), the mean ($\overline{X}$) and the standard deviation (s) are shown for each station. The values for the standard deviations are fairly large in comparison to

Table I Summary of stream water quality data obtained between June and September, 1974.

Station	Mile Point	Soluble Orthophosphate			Total Phosphorus			In Vivo Chlorophyll			Acetone Chlorophyll		
		N	$\bar{X}$	S	N	$\bar{X}$	S	N	$\bar{X}$	S	N	$\bar{X}$	S
Keiss	120.9	42	.196	.187	42	.40	.24	34	227	78	12	.06	.04
30 N B	116.6	42	.14	.11	41	.398	.234	34	425	266	13	.05	.04
Kest	114.7	44	1.44	.94	41	2.19	1.92	35	181	132	13	.02	.01
Denzer	112.4	44	1.28	.77	44	1.74	1.02	35	219	151	13	.03	.03
Shupp	109.6	44	1.24	.78	43	1.64	1.00	34	203	85	13	.03	.03
Caldwell	105.8	46	.828	.52	46	1.25	.500	35	371	274	14	.04	.02
Swartz	98.5	33	.514	.29	34	.908	.366	32	692	448	13	.08	.06
62 B	90.8	39	.273	.167	40	.576	.266	32	676	432	13	.07	.05
CR 55	86.1	41	.181	.164	42	.536	.494	34	724	439	13	.10	.08
30 N Upper	84.7	42	.153	.098	41	.402	.118	33	653	417	13	.11	.07
S-52	80.5	52	.56	.36	50	.85	.48	36	645	377	12	.11	.10
Ind Mill	78.6	42	.38	.26	42	.75	.33	34	655	376	13	.10	.04
SR 67	75.7	41	.27	.14	42	.60	.16	34	687	362	13	.12	.18
SR 103	68.7	42	.18	.30	42	.49	.16	35	822	705	13	.08	.05
S-38	66.7	41	.165	.226	41	.496	.172	33	636	334	12	.08	.05
Camp Pit	58.9	41	.123	.104	41	.378	.150	33	738	358	12	.11	.06
Hecks	55.8	41	.093	.084	42	.300	.078	34	615	516	12	.08	.05
St Johns	51.7	41	.072	.135	41	.227	.210	32	320	206	12	.05	.04
S-26	49.1	45	.082	.132	42	.198	.072	34	351	206	12	.05	.03
Ella	43.0	32	.096	.213	31	.118	.056	23	325	175	9	.05	.03
Huss	40.3	42	.076	.144	38	.198	.075	32	433	345	10	.06	.06
Township	37.5	42	.26	.20	39	.46	.22	31	451	372	9	.06	.07
Ft Seneca	32.8	41	.20	.12	39	.43	.14	31	620	427	10	.10	.08
Old Fort	27.7	43	.13	.10	40	.34	.11	31	584	410	10	.11	.08
Gilmore	25.1	40	.13	.10	39	.32	.10	31	439	417	10	.06	.04
S-10	20.5	49	.113	.09	44	.28	.09	33	378	346	10	.05	.04
Broken Sword*		40	.093	.18	37	.25	.20	32	224	71	13	.02	.02
T-20*		29	.04	.10	31	.14	.06	29	338	187	12	.05	.05
T-12*		31	.536	.321	31	.741	.404	31	169	148	11	.02	.03

* Tributary stations on Tymochtee and Broken Sword Creeks. Station 220 is at Crawford and T-12 is further downstream on Tymochtee Creek below the effluents from Carey, Ohio.

the mean values, reflecting the large variations in concentrations which characterize these parameters. Some of the variation at each station can be accounted for by variation in stream flow but much residual variation exists.

In figure 5a the mean concentrations of ortho and total phosphorus are shown as a function of river miles. The data clearly show the effects on phosphorus concentrations of both sewage treatment plant effluents and in-stream phosphorus deposition. The extremely high concentrations of phosphorus immediately below the Bucyrus sewage treatment plant reflect the low stream flow and attendant lack of dilution of plant effluent which often occurs in the Bucyrus area. The average flow of the Bucyrus sewage treatment plant is listed as 2.55 MGD (3.95 ft^3/s). Table 2 summarizes the streamflow data during the study for the 4 gage stations along the river, as well as for the Tymochtee Creek stream gage.

The decreasing phosphorus concentrations with passage downstream from each town reflect deposition of phosphorus rather than dilution from tributaries with low phosphorus concentrations. This is obvious from examination of maps which show the location of tributaries. It can be proven by comparison of phosphorus fluxes rather than comparison of concentrations. From June 15 through August 7, there was an extended period without significant rainfall and surface runoff. Collections at the stream gages on 17 occasions during this period provided the opportunity to compare fluxes. The average daily flux at Upper Sandusky was 39.8 kg/day; at Mexico, 30 kg/day; and at Fremont 50 kg/day. The average daily stream flows at these stations during this time were: Upper Sandusky, 18.8 ft^3/s; Mexico, 65 ft^3/s; and Fremont, 79 ft^3/s.

The above data show that the phosphorus fluxes actually dropped

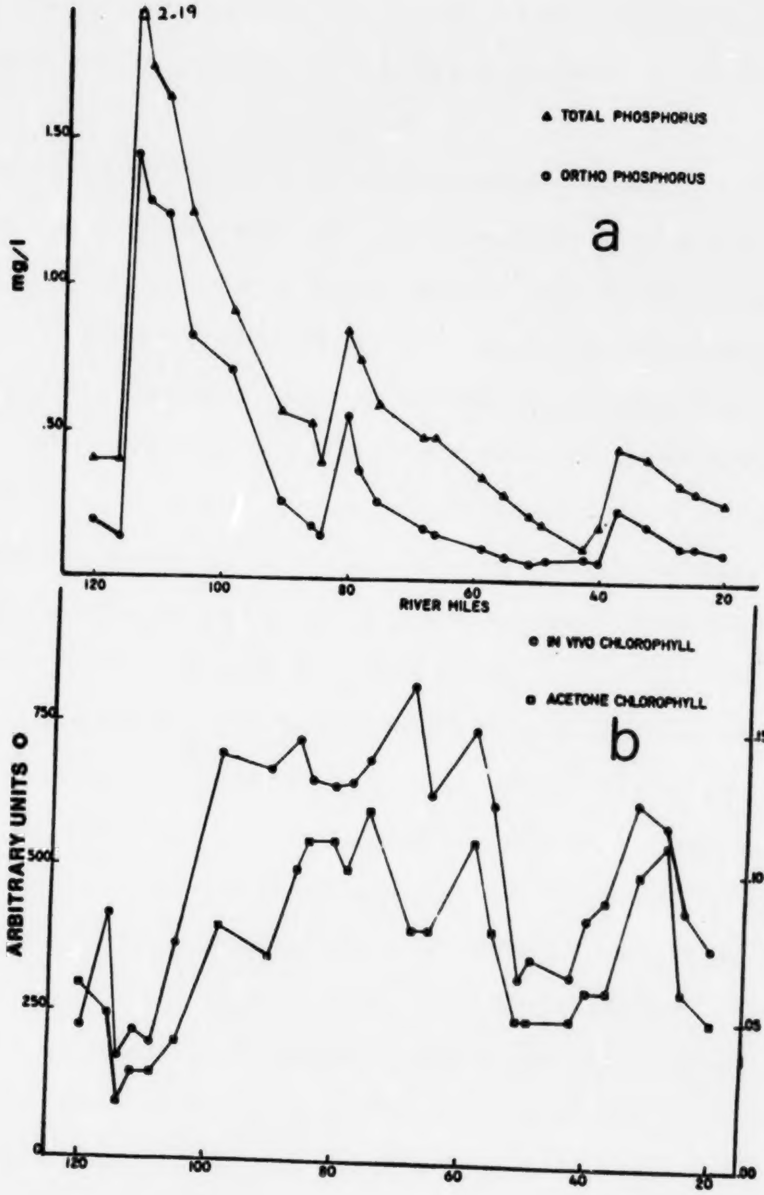

Figure 5. Profiles of mean concentrations of phosphorus and chlorophyll along the river system during June through September, 1974. Mileages shown are the distances from the mouth of the river. The three peaks in phosphorous concentration are caused by the effluents of the Bucyrus, Upper Sandusky anf Tiffin sewage treatment plants. Figure 5a, phosphorus concentrations; Figure 5b, chlorophyll concentrations.

Table 2 Summary of stream flow conditions from June 1 through September 31, 1974 in the Sandusky Basin.

Stream Gage	Drainage Area, mi^2	Flows in ft^3/second			
		Mean	Median	Minimum	Maximum
Bucyrus	88.8	40.5	13	3.2	795
Upper Sandusky	298	52.2	27	5.7	710
Mexico	774	93.1	74	26	790
Fremont	1,251	140.7	91	24	738*
Tymochtee**	229	5.6	2.9	0.3	30

* Excludes first 2 days in June which were on the descending side of a runoff.

** Values are greatly affected by flow augmentation.

between Upper Sandusky and Mexico even though the streamflow increased 3.5 fold. Assuming that the added streamflow contained phosphorus at the same concentration as present in agricultural tributaries, (i.e. 0.15 mg/l), the additional water would have brought in an average of 17 kg per day.

Although the average phosphorus flux at Fremont (50 kg/day) was higher than the flux at Mexico, deposition of phosphorus downstream from Tiffin is obvious from the standpoint of both concentration and flux, since the Tiffin sewage treatment plant has a listed phosphorus loading of about 62 kg/day (Ohio E.P.A., 1974). Keup (1968) and Thomann (1972) have described phosphorus deposition in rivers.

The pattern of average chlorophyll concentrations along the river (figure 5b) shows relatively high values between river mile 100 and river mile 55. A second peak shows up centered at river mile 30. The *in vivo* and acetone chlorophyll values do not mirror one another at all locations. A possible reason is that the values of both show a large amount of variation (see standard deviations in table 1) at each station and *in vivo* chlorophyll was measured much more frequently than was acetone chlorophyll.

Comparing the chlorophyll and phosphorus profiles in figure 6 indicates that in the stretch below Bucyrus, between river mile 115 and 110, the chlorophyll values were the lowest and the phosphorus highest. This merely reflects the extent of organic pollution entering from the Bucyrus sewage treatment plant. The data suggest that chlorophyll peaks are displaced downstream from the sewage treatment plants. At any particular station, plotting the individual point-pairs of phosphorus and chlorophyll give scatter diagrams showing no significant correlation between the two parameters. Comparing chlorophyll concentrations with streamflow at the stream gage sites also indicate no correlation between these two parameters in the low flow range. Chlorophylls are low when stream flows are high.

The average chlorophyll levels do appear to be related to stream gradients along the river. Measurements taken below low head dams are much lower than those taken upstream from the dams. Detailed analyses of the chlorophyll data in relation to stream gradients, inorganic nitrogen forms, conductivities, temperatures and diurnal oxygen fluctuations have not yet been completed. As noted earlier, the diurnal fluctuations in D.O. at Crawford on Tymochtee Creek (station T-20) are much smaller than those at Upper Sandusky (station S-52). The chlorophyll concentrations are much lower at Crawford than at Upper Sandusky.

CONCLUSIONS

The data presented above suggest that the control of D.O. violations associated with diurnal fluctuations can be more effectively achieved through flow augmentation than through phosphorus removal at municiple sewage treatment plants. The effects of flow augmentation appear to be related to physical factors associated with the higher flow, rather than any chemical or biological changes that may accompany the increased flow. The latter conclusion is based on the variability of both nutrient and chlorophyll concentrations which occur within the low flow range.

Studies during the summer of 1975 should provide significant opportunities to check these conclusions. Phorphorus removal will be in operation at both Upper Sandusky and Tiffin during that summer.

ACKNOWLEDGEMENTS

The authors wish to thank the Soap and Detergent Association and the cities of Bucyrus, Tiffin, and Upper Sandusky for providing support for this work. The cooperation of the Ohio Environmental Protection Agency and the U.S. Geological Survey is also greatly appreciated. Portions of the data were obtained during the operation grant Gy-11273 from the Student Oriented Program of the National Science Foundation.

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ABSTRACT

PLANKTONIC CENTRIC DIATOMS FROM THE SANDUSKY RIVER, OHIO

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Plankton was collected from the Sandusky River near Fremont, Ohio in one liter surface grab samples biweekly from October 14, 1973 to May 26, 1974. Following concentration by sedimentation the samples were studied in a Palmer Cell and the standing crops of centric diatoms were recorded. Centric diatoms observed in the samples were *Cyclotella atomus, C. cryptica, C. meneghiniana, C. pseudostelligera, C. stelligera, Melosira granulata, M. varians, Microsiphona potamos, Stephanodiscus astrea* var. *mintula, S. hantzschii, S. invisitatus,* and *Thalassiosira pseudonana*.

Some taxonomic problems were encountered in the course of this study. *Stephanodiscus invisitatus* and *S. hantzschii* were separated on the courseness of the striae although some overlap did occur. *Cyclotella meneghiniana* and *C. cryptica* were separated on the basis of relative breadth of the marginal zone and the eveness of the marginal-central border. We feel that these two "species" and *C. atomus* are all closely related and the "meneghiniana complex" requires further detailed evaluation.

The fall collections were dominated by *Cyclotella atomus* with over 41 x 10^3 cells/ml on 10-14-73. The spring samples were dominated by *Stephanodiscus invisitatus* with over 49 x 10^3 cells/ml on 4-28-74. Most *Cyclotella* species reached maximum abundance in the fall while all *Stephanodiscus* species reached maximum abundance in spring.

PLANKTONIC CENTRIC DIATOMS OF THE SANDUSKY RIVER NEAR FREMONT, OHIO

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INTRODUCTION

Centric diatoms are often the most abundant group of river phytoplankters. In the Little Miami River at Cincinnati centric diatoms represented 63% of the yearly average standing crop of phytoplankton (Weber and Moore, 1967). Wager and Schumacher (1970) indicated that the centric genera *Cyclotella* and *Stephanodiscus* were dominant diatoms from the phytoplankton of the Susquehanna River near Sayre, Pennsylvania. *Stephanodiscus* was the most abundant phytoplankter in samples from Pool 19 of the Mississippi River (Gale and Lowe, 1971). Hynes (1970) discusses the importance of centric diatoms in river phytoplankton in general.

Many of the centric diatom species abundant in river plankton communities are relatively small, often less than 5 μm in diameter. The small size, fine ornamentation, and morphological similarity of small centric diatom species makes enumeration difficult. This is particularly true when several species occur together.

The objectives of this study were to determine the species of centric diatoms present and their absolute abundances in a portion of the Sandusky River for a seven-month period.

MATERIALS AND METHODS

The Sandusky River is in north-central Ohio and drains approximately 3.7×10^3 km^2 of primarily agricultural land. The river flows into Sandusky Bay of Lake Erie. Samples for phytoplankton analysis were collected as one liter whole water surface grab samples approximately 10 km upstream from Sandusky Bay. Collections were made from October 14, 1973 through May 26, 1974. The samples were preserved with Lugol's iodine and concentrated by sedimentation in one liter graduated cylinders. Phytoplankton was concentrated 10 to 50 fold, depending on the initial density, to facilitate analysis. Samples were analyzed for standing crop employing a Palmer-Maloney (P-M) nannoplankton cell and a Bausch and Lomb research microscope. When possible at least 500 centric diatoms were counted from each sample. In several collections the low levels of centric diatoms prevented the enumeration of 500 specimens. The standing crop of centric diatoms was calculated with the following formula:

$$\text{centric diatoms/ml} = N(VC)^{-1}$$

N = number of centrics counted in Palmer-Maloney Cell

V = volume of concentrate counted in Palmer-Maloney Cell

C = concentration of plankton sample (initial vol./final vol.)

A portion of each plankton sample was cleaned with 30% H_2O_2 (Werff, 1955) and mounted in Hyrax (Custom Research and Development Inc., Auburn, Cal.) for species identification.

Each of the mounted samples was scanned under oil immersion (total mag. = 1000) and the first 500 centric diatom specimens were identified and recorded. The standing crop in cells/ml was calculated for each species in each sample.

In certain instances electron microscopy was employed to facilitate species identification. Specimens were prepared for transmission electron microscopy (TEM) by dropping a suspension of H_2O_2 cleaned diatoms on a formvar coated copper grid. A Hitachi HS-8F-1 transmission electron microscope operating at 75 kv was used to observe and photograph the specimens. Scanning electron microscopy (SEM) was accomplished on a Hitachi Hiscan HHS-2R scanning electron microscope operating at an accelerating voltage of 25 kv. Specimens were prepared by H_2O_2 cleaning. They were then strewn on an aluminum specimen stub and coated with $\sim 1.5 \times 10^{-8}$m of gold in a glow discharge coater.

RESULTS

A total of 12 taxa of centric diatoms was observed during the study. Each of the taxa will be considered separately.

Cyclotella atomus Hust.

This species occurred in maximum abundance during the initial sampling period of October 14 (fig. 2). At this time the population comprised 94% of the centric diatoms present with a standing crop of 3.9×10^4 cells/ml. The population remained below 50 cells/ml from December 9 through April 28 and increased slightly in May.

Cyclotella meneghiniana Kütz.

Cyclotella meneghiniana occurred in maximum numbers in the fall (fig. 2) reaching a maximum standing crop of 1.5×10^4 cells/ml on October 28. This species was present in relatively low numbers from December 9 through April 14. A pulse was observed in the spring but in numbers lower than those observed in early fall.

Cyclotella pseudostelligera Hust.

This species was never a very numerically significant member of the plankton community (fig. 1). A maximum standing crop of 2.4 X 10^2 cells/ml was observed on April 28.

Cyclotella stelligera Cl & Grun.

The maximum standing crop was recorded on October 28, 1.5 X 10^3 cells/ml (fig. 1). This species was present in relatively low numbers during the winter with a slight increase in May.

Melosira granulata (Ehr.) Ralfs

A single pulse of this taxon was recorded on October 28 (fig. 1). On this date a standing crop of 5.8 X 10^2 cells was observed. *Melosira granulata* was either absent or present in low numbers at other times.

Melosira varians Ag.

This species was never a numerically significant component of the phytoplankton community. Two small maxima were observed (fig. 1). The larger maximum was 3.8 X 10^2 cells/ml on October 28.

Microsiphona potamos Weber

No published report of the occurrence of this taxon has appeared since it was first describud by Weber (1972). *Microsiphona potamos* displayed both fall and spring maxima (fig. 2). The spring maximum, 1.4 X 10^4 cells/ml, was the larger and was recorded on May 12.

Stephanodiscus astraea var. *minutula* (Kütz.) Grun.

This taxon was not very abundant in any sample but a small spring maximum of 75 cells/ml was observed on May 12.

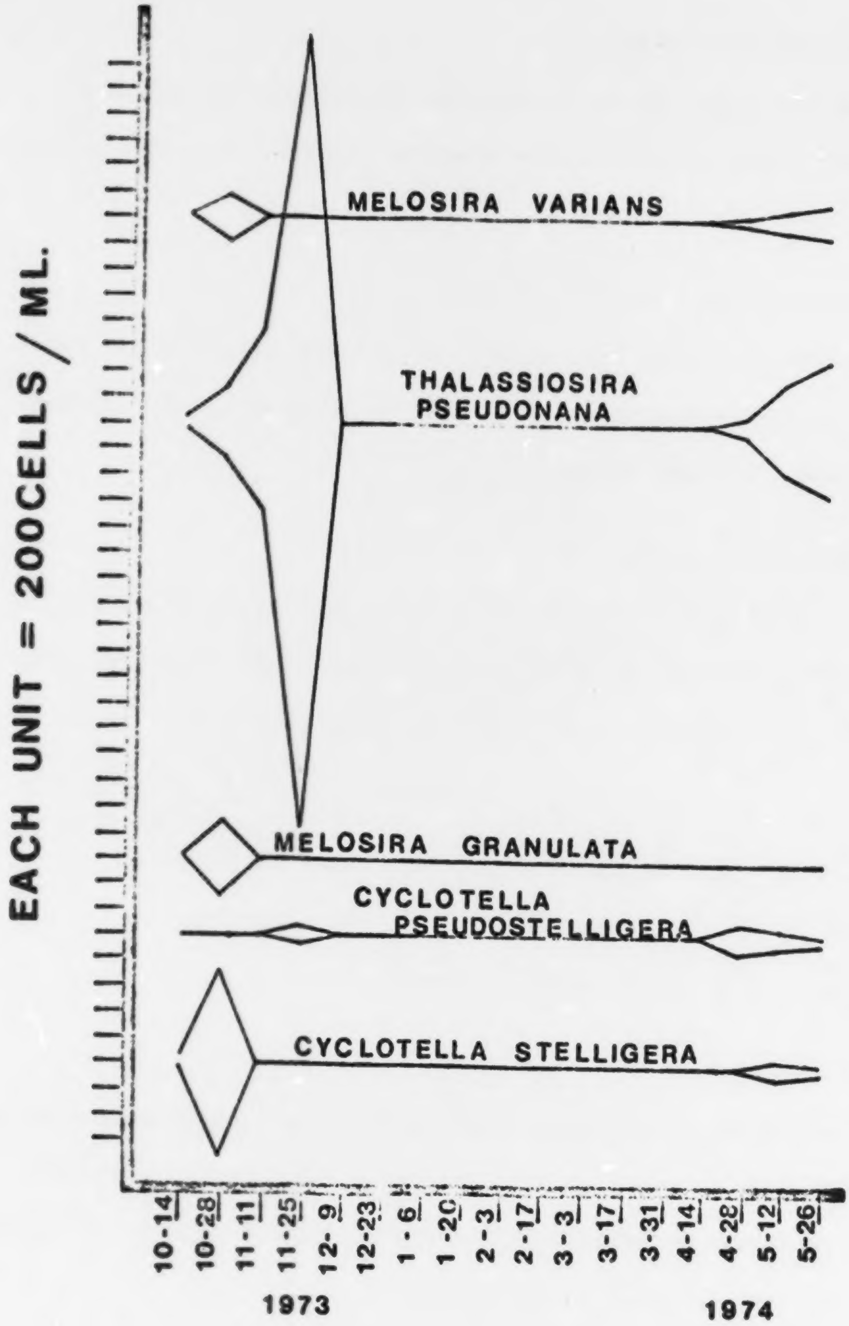

Fig. 1 Standing crops of species of centric diatoms in the Sandusky River near Fremont, Ohio.

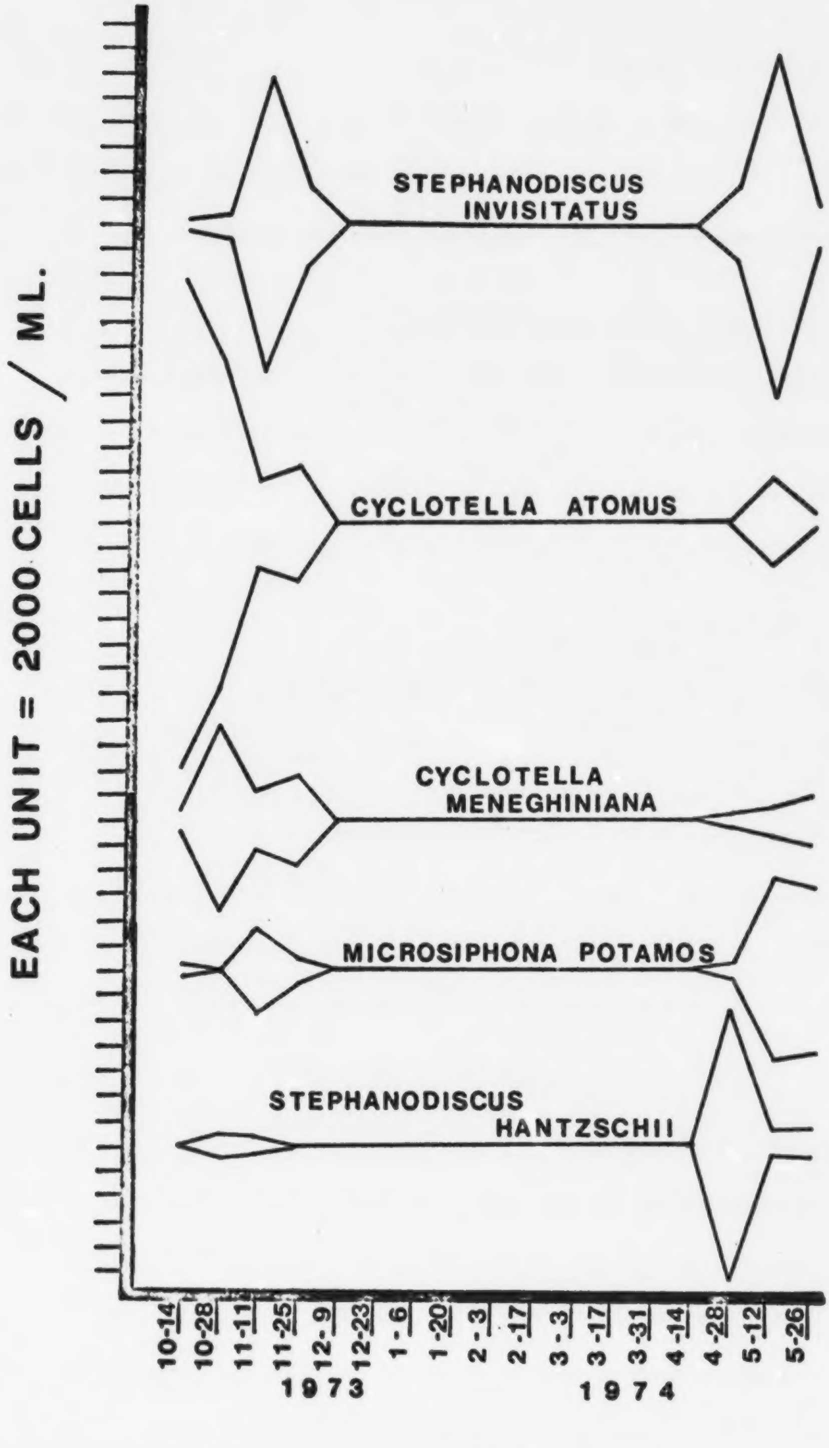

Fig. 2 Standing crops of species of centric diatoms in the Sandusky River near Fremont, Ohio.

Stephanodiscus hantzschii Grun.

This species displayed a spring maximum of 2.2 X 10^4 cells/ml on April 28 (fig. 2). A relatively smaller pulse was observed in the fall and the population remained at very low levels during the winter.

Stephanodiscus invisitatus Hohn and Hellerman

Stephanodiscus invisitatus displayed both spring and fall maxima (fig. 2). The largest standing crop 2.6 X 10^4 cells/ml was observed on May 12. With the exception of *Cyclotella atomus, S. invisitatus* was the most numerically important centric diatom in the plankton.

Thalassiosira fluviatilis Hust.

Very few specimens of this taxon were observed with no noticeable seasonal maxima.

*Thalassiosira pseudonana (*Hust.) Hasle and Heimdal

This species reached maximum abundance, 6.3 X 10^3 cells/ml, on November 25. The population remained at relatively low levels from December 9 through April 14. A spring maximum was recorded on May 26.

DISCUSSION

The species of planktonic centric diatoms encountered in the Sandusky River are typical components of alkaline midwest rivers. *Cyclotella atomus,* the most abundant fall species in this study, is a widely distributed component of river plankton (Weber, 1966). In the Sandusky River it is also present in large numbers in the periphyton. Since the river is relatively shallow there is probably a good deal of exchange of unicellular algae between the periphyton and phytoplankton. *Stephanodiscus invisitatus* was another numerically important species in the plankton. Weber (1966) considers it an important component of the Ohio River Basin. I have observed this species in abundance from rivers in Pennsylvania, Indiana and Iowa.

Several interesting observations on seasonal species distribution were noted (figs. 1-2). With the exception of *Cyclotella pseudostelligera,* a numerically insignificant community member, all species of *Cyclotella* were more abundant in autumn than in spring. *Stephanodiscus* species were most abundant in spring. The bulk of the spring pulse was comprised of *S. invisitatus*. *Microsiphona potamos* was also an important spring component.

Several of the species in this study presented some taxonomic difficulty. *Stephanodiscus invisitatus* is very similar to *S. hantzschii*. The relationship is such that *S. invisitatus* should probably be considered a variety of *S. hantzschii*. Weber noted (personal communication) that these two could be separated on the coarseness of the striae, *S. hantzschii* being the coarser of the two. We separated the two species primarily on this character but we observed, as did Weber, that morphological intermediates between *S. hantzschii* and *S. invisitatus* do exist.

The abundance of *Microsiphona potamos* in our samples leads us to believe that it is being overlooked or misidentified in many river plankton surveys. We were not aware of it until observations with electron microscopy.

ACKNOWLEDGEMENTS

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ABSTRACT

SEASONAL DISTRIBUTION OF PERIPHYTIC DIATOMS COMMUNITIES OF TYMOCHTEE CREEK

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Periphyton communities have been used increasingly with wide application in the assessment of water quality. The community has been investigated on the basis of species diversity and water quality indicator organisms, Diatoms are the organisms most frequently monitored as representatives of periphyton communities.

The stream under investigation is Tymochtee Creek, a major tributary of the Sandusky River. The creek has a total length of 88.3 kilometers, and the one station involved in this analysis is located 76.3 kilometers from the mouth. The sampling period extended from May 26, 1974 to March 6, 1975. Samples were collected from the stream by using a quantitative sampler designed and developed by Aquatic Specialities, Berwick, Pennsylvania. Collected samples were stained with acid fuschin and a technique developed by Brad Owens, Jr., NUS, Pittsburg, Pennsylvania. Final stained samples were decanted to a 5 milliliters volume from which slides were made. Counts were completed by scanning from one side of the cover slip to the other. Crosses were continued until 500 cells had been counted. All crosses were completed once started.

The ornamentation of the inert silica cell wall of diatoms is important in taxonomy. It is therefore common to remove all organic material from the cells allowing the ornamentation to be clearly seen. The removal or organic material prior to the determination of live and dead cell numbers cause an error in determining species diversity in their use as indicator organisms.

A somewhat wide variation existed in the percentage composition of live and dead cells. In the spring collection, May 26, 1974, a cell count of 710 cells showed 69% of the cells had protoplasm present (live cells) and 31% were empty frustules; summer collection, August 23, 1974, a count of 754.5 cells was made up of 52% live cells and 48% dead cells; a fall collection, November 24, 1975, with a cell count of 502.5 cells had 65% live cells and 35% dead; and a winter collection, March 6, 1975, had a cell count of 550 cells made up of 87% live cells and 13% dead cells.

SEASONAL DISTRIBUTION OF PERIPHYTIC DIATOM COMMUNITIES OF TYMOCHTEE CREEK

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INTRODUCTION

Periphyton refers to those organisms present upon, but not penetrating, submerged surfaces; here interest is directed to periphyton on natural rock substrates (epilithic). Periphyton floral communities are important in aquatic environments because they represent primary producers for a complex food web; and, in most instances, diatoms represent the dominant members of the periphyton. Diatoms have certain characteristics which facilitate their use in water quality analysis:

- Diatoms are relatively easy to collect, prepare for observation, identify, and store.
- Diatoms are one-celled organisms in constant exposure to the environment.
- Diatoms are cosmopolitan.
- Diatom community structure lends itself to species diversity analysis.

For these and other reasons diatoms have been used in the assessment of water quality. Some people have used the autecology of diatoms from bog or lake core samples to describe or imagine preglacial conditions (Patrick, 1954; Collins, 1967). Lowe (1974) compiled, from the literature, information about ecological limitations of many diatom species, and this information may be useful in determining water quality, within a sampled area, by compiling the autecological information for the diatoms sampled from that area.

Similarly, the structure of periphyton communities is useful in determining the "health" of an aquatic environment. Periphytic diatom communities on natural substrates have been studied with scattered success for quantifying the results (Douglas, 1958; Jones, 1974). Patrick _et_ _al_. (1954) reported a floating sampler which would collect periphyton on glass slides. The periphyton could then be analyzed qualitatively or quantitatively. Patrick _et_ _al_. (1954) also mentioned a method of analyzing the diatom community structure in such a manner to give optimum information about the community and thus about the environment. The procedure would yield comparative data between different environments within a stream and also between streams of similar types (Patrick and Strawbridge, 1963). Quantitative samples may be analyzed by using any one of several diversity indices. Patrick (1973) suggested the total structure of a community be analyzed in terms of numbers of species, relative abundance of species, kinds of species, and total biomass present.

Biomass determinations concern the living component of the community structure, or that part which is actively involved within the community. Most diatom identifications are done using cleaned material which have had the protoplasm removed, thus there is no way of determining the active components of the system. Weber (1970) used fragments of protoplasm in diatom frustules from uncleaned samples as an indication of a live cell. He was able to determine live and dead cell ratios for the genus level of taxonomy. Since the autecology of a diatom concerns the individual species, we needed a greater effort of identification to the species level in order to use the known autecology for diatoms effectively.

METHODS

Stream

Tymochtee Creek is 88.3 km long and is one of the major tributaries of the Sandusky River. There are no large municipalities within the Tymochtee Basin, which is mainly used for agriculture; hence, the stream usually carries a high silt load. An upland reservoir, located in Killdeer Wildlife Refuge, Wyandot County, Ohio, serves the Sandusky River for low-flow augmentation.

Stations were designated by kilometers from the mouth of the creek, and the station in this report is 76.3 (figure 1). The area sampled was a pool area immediately downstream from a bend in the creek. This part of the stream lies within the boundaries of a pasture.

Collection

Samples were collected on a seasonal basis from May 26, 1974 through March 6, 1975. Samples were collected from natural rock substrates at the station by a quantitative sampler designed and produced by Aquatic Specialties, Berwick, Pennsylvania (figure 2). The device, a modified craftman's woodclamp, is designed to seal a sample of a known area on the substrate while the substrate is present on the stream bottom. This method allows a collection of the periphyton community with very little disruption to the community structure. The sample, once sealed, was removed from the bottom, marked for later identification, and then transferred to the lab.

Sample Preparation

The periphyton was removed from the sealed area via the access holes, loosened by scraping the surface with dental picks, and then washed into

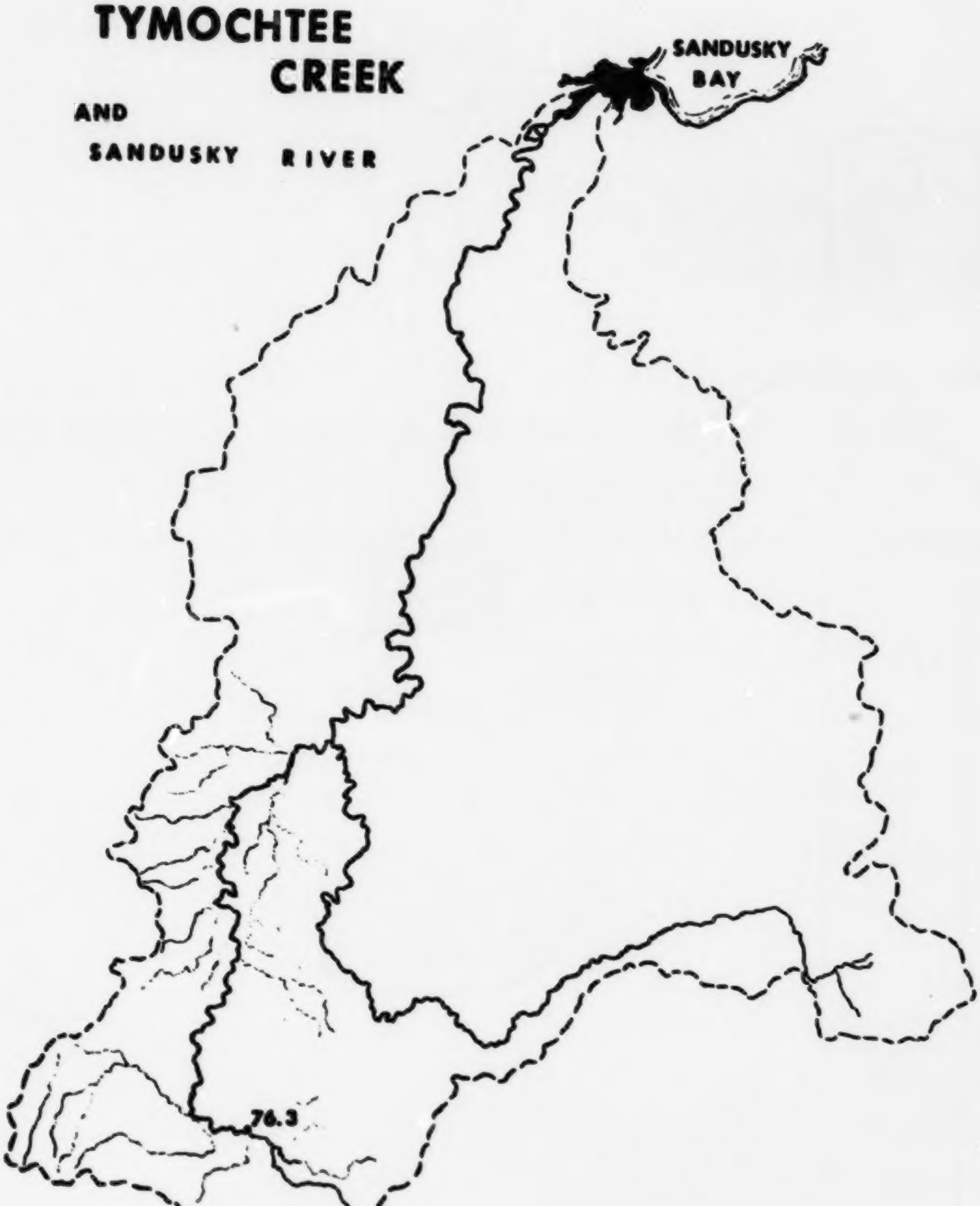
TYMOCHTEE CREEK
AND
SANDUSKY RIVER
SANDUSKY BAY
76.3

Figure 1 - Location of Station in the Sandusky River Basin

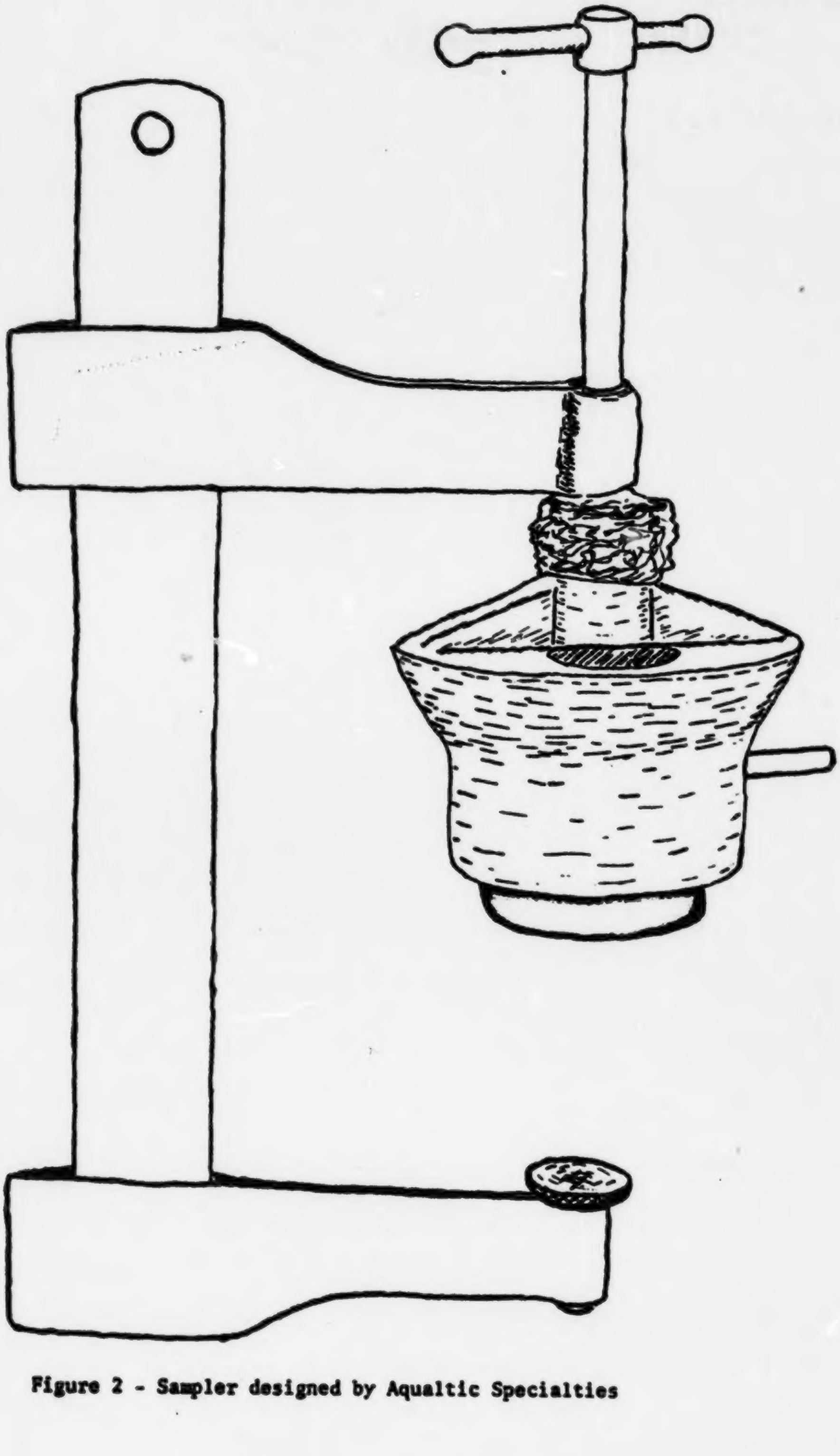

Figure 2 - Sampler designed by Aqualtic Specialties

storage vials. The material was settled in the vials for a period greater than 24 hours; then the volume was decreased to 10 milliliters. The 10-ml sample was shaken to uniformly distribute the material, and divided into 2-5-ml volumes. One 5-ml sample was processed through an acid fuschin staining technique (Bradford B. Owens, Jr., personal communication, 1974), and the other 5-ml sample served as a safeguard against sample loss in the staining procedure.

Samples were stained, dehydrated, and then transferred to a xylene solution according to the technique. Slides were prepared by adding a known volume of the stained material to a cover slip. The cover slip and material were air-dried, inverted onto Hyrax on a labelled slide, and then heated to drive off the solvent of the Hyrax. Slides were then scraped to clean off excess Hyrax, and an identifying label was attached to each slide.

Counting Procedure

Counts of at least 500 cells (1000 valves) were completed by counting diatoms observed during a cross of the prepared slide while observing under oil immersion (1000X). All diatoms were identified to species and noted whether live or dead. Live cells had stained protoplasm present, and dead cells were colorless. The initial starting point for counting was randomly selected on the slide and marked by drawing a line with a diamond scribe across the cover slip. The initial crossing of the cover slip was made by placing the inscribed line at the bottom of field view under oil immersion and then scanning the slide from left to right. Each successive strip crossing (if needed) was made by moving one field view up from the previous crossing and then scanning back over the slide.

RESULTS

A cell count for the May 26, 1974 sample was made up of 710 cells; 487 (69%) were live cells and 31% were dead cells. Of the 50 taxa identified for the total cell count, 27 taxa were represented by live specimens.

A cell count for August 23, 1974 sample was made up of 754.5 cells; 394 (52%) were live cells and 48% were dead cells. Of the 55 taxa identified for the total cell count, 43 taxa were represented by live specimens.

A cell count for November 24, 1974 sample was made up of 502.5 cells; 328 (65%) were live cells and 35% were dead cells. Of the 52 taxa identified for the total cell count, 28 taxa were represented by live specimens.

A cell count for the March 6, 1975 sample was made up of 550 cells; 477 (87%) were live cells and 13% were dead cells. Of the 29 taxa identified for the total cell count, 28 taxa were represented by live specimens.

A total of 82 taxa was identified (table 1); 68 (83%) taxa were represented by live specimens, and of the 82 taxa identified 12 were common to each sampling period.

DISCUSSION

Techniques

Every sampler is designed to meet specific requirements, and thus every sampler has built-in limitations. This sampler is no different. The sampler is designed to clamp on to a rock substrate that is fairly even; therefore, it works fine in streams which have shelving rock (of a reasonable size to handle easily). It is very difficult to use the sampler on rocks that are irregular or extremely thick.

Table 1: Species List: Seasonal Distribution & Relative Abundance

Genus & Species	Spring Live Cells	 Total Count	Summer Live Cells	 Total Count	Fall Live Cells	 Total Count	Winter Live Cells	 Total Count
*Cyclotella atomus**	-	-	UC	UC	-	-	-	-
*Meneghiniana**	R	R	R	UC	R	R	-	-
*pseudostelligera**	-	-	-	R	-	-	-	-
*stelligera**	-	R	-	-	-	-	-	-
*Melosira varians**	-	-	-	-	UC	UC	-	-
*Stephanodiscus invisitatus**	-	R	-	-	-	-	-	-
*Fragilaria pinnata**	A	A	R	R	UC	UC	C	C
*Achnanthes affinis**	R	UC	-	-	-	-	R	R
*lanceolata**	R	UC	-	R	R	UC	UC	C
Cocconeis placentula	UC	UC	-	R	-	-	R	R
*Rhoicosphenia curvata**	R	UR	-	-	R	R	UC	UC
Amphora bullatoides	-	-	R	R	R	R	-	-
*ovalis var. lybica**	-	-	R	R	R	R	-	-
*ovalis var. pediculus**	UC	UC	-	R	R	R	C	A
perpusilla	R	R	-	-	R	R	UC	UC
*Cymbella sinuata**	R	R	-	-	-	-	-	-
triangulum	-	R	-	-	-	-	-	-
*turgida**	R	R	-	-	-	-	-	-
*Denticula elegans**	-	-	-	R	R	R	-	-
Diploneis puella	-	-	R	UC	-	-	-	-

Table 1: Continued. Species List: Seasonal Distribution & Relative Abundance

Genus & Species	Spring Live Cells	Spring Total Count	Summer Live Cells	Summer Total Count	Fall Live Cells	Fall Total Count	Winter Live Cells	Winter Total Count
Frustulia rhomboides var. *sax.*	-	-	-	-	-	R	-	-
*Gomphonema gracile**	-	-	-	-	-	R	-	-
longiceps	R	R	-	-	-	-	-	-
*olivaceum**	-	R	-	-	-	-	-	-
*parvulum**	-	-	-	-	R	UC	R	R
*Navicula capitata**	R	R	-	R	R	UC	-	-
cryptocephala var. *veneta**	-	R	UC	UC	R	UC	R	R
gottlandii	-	-	-	-	R	UC	-	-
halophilous	-	-	-	R	-	-	-	-
*lanceolata**	-	R	R	R	R	UC	-	-
*luzonensis**	-	R	-	-	-	-	-	-
menisculis var. *upsaliensis*	-	-	-	-	UC	UC	R	R
*notha**	-	-	UC	C	UC	UC	R	UC
pupula var. *eliptica*	-	-	-	R	R	R	-	-
radiosa var. *tenella**	R	R	-	R	UC	UC	R	R
secreta var. *apiculata*	R	UC	R	UC	UC	C	UC	C
symmetrica	-	-	UC	UC	R	UC	-	-
tenera	-	R	R	R	-	-	-	-
tripunctata	R	R	UC	UC	R	UC	R	R
*viridula**	-	R	R	R	R	R	-	-
*Nitzschia acicularis**	R	UC	-	-	-	-	-	-
acuta	-	R	-	R	R	R	-	-
*amphibia**	-	-	-	-	R	R	R	R

Table 1: Continued, Species List: Seasonal Distribution & Relative Abundance

Genus & Species	Spring Live Cells	 Total Count	Summer Live Cells	 Total Count	Fall Live Cells	 Total Count	Winter Live Cells	 Total Count
*Nitzschia apiculata**	-	R	R	R	C	C	-	R
Bacillariaeformis	-	-	-	-	R	R	-	-
*communis**	-	R	-	-	-	-	-	-
*dissipata**	UC	UC	R	R	C	C	A	A
epiphytica	-	-	A	A	R	R	-	-
etoschensis	-	-	R	UC	-	-	-	-
*fonticola**	-	-	R	UC	R	UC	-	-
frustulum var. *perpus.**	R	R	R	R	UC	UC	UC	UC
intermissa	-	R	R	R	-	-	-	-
latens	-	-	UC	C	C	C	UC	UC
mollis	R	R	-	-	-	-	-	-
osomophila	-	-	UC	UC	R	UC	-	-
*palea**	-	R	C	A	UC	UC	-	-
*parvula**	-	-	-	-	-	-	R	R
pubens	-	-	R	R	-	-	-	-
rachenbachiae	-	-	UC	UC	R	R	-	-
recta	-	-	-	-	R	R	-	-
*sigma**	R	R	R	R	R	R	-	-
silingue		R	-	-	-	-	-	-
spiculoides	-	R	-	-	-	-	-	-
Steynii	-	-	-	-	-	R	-	-
tryblionella var. *victoriae**	R	R	-	-	-	-	R	R
valga	-	-	R	UC	R	UC	-	-
*Cymatopleura solea**	-	R	-	-	-	-	-	-

*Surirella angustata**		-	R	R	R	R	R	-	-
iowaensis		-	R	-	-	-	R	-	-
*ovata**		UC	C	-	R	UC	UC	-	-
Unidentified Specimens									
Centrics	@3u - 5u in diameter	-	-	R	UC	UC	UC	UC	UC
(Nav?)	20u - 18uX 16 in 10u	R	R	-	-	-	-	UC	UC
	30u - 40uX 16	-	-	R	R	UC	C	-	-
	9u X 30 X 4u	R	UC	R	UC	UC	UC	A	A
	@36u X 12 X 8u	-	-	R	R	R	UC	-	-
(Nitz?)	23uzX 12 X 30-35 X 5u	-	R	-	R	-	-	-	-
	24u X ii	-	-	UC	UC	UC	UC	R	R
	24u X 17	R	R	-	-	-	-	-	-
	26u X 14 X 35-40 X 5u	-	R	-	-	-	-	-	-

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* Species was used in the compilation of information

- No cells counted, not present

R Rare, represents less than 1% of the total count

UC Uncommon, represents 1-5% of the total count

C Common, represents 5-10% of the total count

A Abundant, represents 10% or greater of the total count

The staining technique is relatively easy to use, and I encountered no severe problems. Slide preparation requires some mastering since fine pieces of rock material are initially scraped and washed off with the periphyton. The rock pieces become spacers when preparing a slide, thus a slide may have three or four focal planes or diatoms may be in girdle or a canted view. With some practice, the severity of spacing may be decreased.

Results

Using the work by Lowe (1974), I matched the species I identified to those listed by Lowe. I used these "matched" species to compile autecological information. Each parameter was represented by the cell numbers for that species; i.e., 26 cells of *Melosira varians* Ag. were identified in the fall sample; this diatom is listed by Lowe under the Halobion spectrum as indifferent; therefore, indifference in the Halobion spectrum is represented by 26 cells. Similarly, each species' (resulting from the match) parameter summarized by Lowe was represented by the cell numbers I counted for that species. Then I simply added all the cell numbers representing each parameter. I went through this whole procedure several times; once for total and live cell representation (table 2), and again for a seasonal live cell distribution (table 3).

A problem arises in interpreting the data because the information is about the individual diatom species not the stream; therefore, I assumed the higher numbers of cells for a parameter indicated the translation of that parameter must be effective within the stream at the time of sampling; i.e., a high number of cells totaled for acidiphilous, I would assume a stream pH of seven or below to be in effect within the stream at the time of sampling.

The tallied total cell numbers and living cell numbers, resulting from

Table 2: Total Cell Number and Living Only Cell Number Spectrum Analysis

Spectrum	Total Cell Numbers	Living Cell Numbers
pH		
Indifferent	196.5	124
Alkaliphilous	1174	905
Alkalibiontic	250	208
Nutrient		
Eutrophic	1015	795
Halobion		
Mesohalobous	94.5	64
beta range	1	1
Oligohalobous	45	28
halophilous	39.5	22
indifferent	1208.5	924
halophobous	9.5	7
Euryhalobous	13	10
Saprobien		
Polysaprobic	107	63
Mesosaprobic	302.5	161
alpha range	103	76
beta range	632	529
Oligosaprobic	679.5	546
Saprophilic	23	18
Saproxenous	23	18
Saprophobic	24	19

Table 2: Continued

Spectrum	Total Cell Numbers	Living Cell Numbers
Current		
Limnobiontic	507	428
Limnophilous	527.5	437
Indifferent	860.5	669
Rheophilous	413	301
Rheobiontic	87.5	57
General Habitat		
Lake	926.5	745
Pond	926.5	745
River	21.5	10
Spring and Stream	211.5	146
Aerophilous	103.5	79
Specific Habitat		
Euplanktonic	32	14
Tychoplanktonic	137	69
Periphytic	1095	897
epiphytic	120.5	87
Temperature		
Mesothermal	233	204
Oligothermal	300.5	226
Metathermal	5	4
Eurythermal	428.5	300

Table 3: Spectrum Analysis for Seasonal Distribution of Living Cells

Spectrum	5/26/74	8/23/74	11/24/74	3/6/75
pH				
Indifferent	7	56	55	6
Alkaliphilous	459	31	134	281
Alkalibiontic	11	6	36	155
Nutrient				
Eutrophic	398	84	91	222
Halobion				
Mesohalobous	1	16	45	2
beta range	-	-	-	1
Oligohalobous	-	14	10	4
halophilous	-	14	5	3
indifferent	461	79	101	283
halophobous	6	-	-	1
Euryhalobous	7	1	1	1
Saprobien				
Polysaprobic	-	54	9	-
Mesosaprobic	24	59	22	56
alpha range	26	-	1	49
beta range	411	4	27	87
Oligosaprobic	418	5	13	110
Saprophilic	17	-	-	1
Saproxenous	17	-	-	1
Saprophobic	18	-	-	1

Table 3: Continued

Spectrum	5/26/74	8/23/74	11/24/74	3/6/75
Current				
Limnobiontic	381	4	6	37
Limnophilous	385	7	8	37
Indifferent	413	64	90	102
Rheophilous	30	3	83	185
Rheobiontic	5	15	11	26
General Habitat				
Lake	391	81	79	194
Pond	391	81	79	194
River	-	10	-	-
Spring and Stream	14	19	37	76
Aerophilous	9	14	6	50
Specific Habitat				
Euplanktonic	4	10	-	-
Tychoplanktonic	1	55	12	1
Periphytic	436	94	94	273
epiphytic	27	-	3	57
Temperature				
Mesothermal	11	1	37	155
Oligothermal	25	2	44	155
Metathermal	-	4	-	-
Eurythermal	26	56	55	163

the above procedure, seem to mirror or reinforce one another throughout the parameters. Numbers indicate the pH of the stream is slightly alkaline; nutrients are rich; salt concentrations may be present (indicated by the greater number of cells toward Mesohalobic conditions); the saprobien spectrum boarders between an oligosaprobic to beta-mesosaprobic conditions; current appears to be of standing water or slightly moving water; general habitat agrees with the current spectrum; specific habitat was periphytic; and the temperature fluctuations within the stream are 15° or over. These characteristics are pretty much in effect within the area sampled.

The Tymochtee stream bed is largely dolomite bedrock, and stream fluctuations in the pH are mainly between seven and eight. The stream basin is largely agricultural with high amounts of phosphates and nitrates being washed into the stream. The salt concentration is low; however, specific conductivity may become quite high at times and affect the flora in the same manner as salt. The station is within a pasture, and a wide range of nitrogenous compounds may be found within the stream, possibly supporting mesosaprobic conditions. Current and general habitat are exactly what was indicated, slightly moving or standing water. Specific habitat was correct; periphytic, and normal temperature fluctuations are over 15° C within a year.

Results of the seasonal distribution of live cells, in a similar analysis, do not show any sharp change in the pH spectrum or the nutrient spectrum. In the halobion spectrum there appears to be somewhat of a seasonal fluctuation occurring. During the spring more cells toward the halophobous spectrum are present: in the summer and fall greater cell numbers are in the mesohalobous spectrum and none is present in the halophobous spectrum. This may indicate an increase in the specific conductance of the stream for the summer and fall.

The saprobien spectrum boarders also on oligo-mesosaprobic condition; however, in the spring sample period saprophilic and saproxenous diatoms are found. Numbers are low, but in the winter almost the same conditions exist. In each sampling period, spring and winter, high water conditions had occurred previously in the stream. Assuming scouring of the rock substrate had occurred and concentrations of nitrogenous compounds were low, I thought this might indicate the invasion of a new habitat might be occurring, at least initially. The same may be true for the presence of rheophilic forms in the winter and spring, and also for the presence of aerophilous diatoms in the winter.

Other general habitat information agrees with total cell analysis and actual conditions. The specific habitat information also reflects total cell trends; however, the epiphytic spectrum is divided into the spring and winter periods. These numbers may indicate some ersatz species invading the habitat, or more than likely the presence of algal filaments known to proliferate in early and late spring.

The temperature spectrum agrees in part with the total cell information.

SUMMARY

Sufficient information about the autecology of diatoms is present to warrant their use as water quality indicator organisms. The stream conditions that do exist in Tymochtee Creek are described fairly well by the compiled numbers and autecology of the diatoms present. Although there appears to be no significant difference between the information accumulated for living cell numbers and total cell numbers, there may be two important factors acting here.

One factor is the total number of species listed in this report and used in the compilation of information was 39, or 48% of the total taxa identified--less than half of the total identified cells. Add to it that during three of the sampling periods greater than 30% of the cells were dead. Weber (1970) indicated an average dead cell portion of 32% creates a serious weakness in the data. So only a percentage of the total cells counted was used.

A second factor that may be acting here is the number of cells counted. Patrick (1973) indicated that too often counts are limited to too few numbers without testing the reliability of these numbers to reflect the community structure. An increase in the number of cells counted would give more live cells on which to base any indications.

I do think it is important to distinguish between live and dead cells within a sampled periphyton community. I especially think it is a must when diatoms are used as water quality indicator organisms, since only the live cells represent the active part of the community.

ACKNOWLEDGEMENTS

I want to thank Dr. Rex L. Lowe for helping me with identifications and my problems that I encountered, in more ways than one. I want to also thank my friends Frank Acker and Jan Stevenson for their help, and special thanks to Bayliss Prater.

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ABSTRACT

PHYTOPLANKTON OF THE SANDUSKY RIVER NEAR FREMONT, OHIO

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A survey was taken to provide a taxonomic list of algae and to determine seasonal trends and spatial differences in the phytoplankton community in a segment of the Sandusky River at Fremont, Ohio.

Phytoplankton samples were collected biweekly from October 14, 1973 through May 26, 1974. A total of 265 algal taxa were identified employing a Palmer-Maloney counting slide and Hyrax-mounted slides. Diatoms (Bacillariophyceae) dominated the phytoplankton community throughout the study, ranging from 68 percent to 93 percent of the phytoplankton. Standing crop values showed autumnal and spring maxima separated by a period of low phytoplankton numbers with a few euplanktonic forms present. The autumn pulse was dominated by the centric diatoms *Cyclotella atomus* and *C. meneghiniana*. *Stephanodiscus invisitatus, Stephanodiscus hantzchii* and *Microsiphona potamos* dominated the spring maxima. Standing crop values ranged from 101 cells per milliliter to 83,063 cells per milliliter.

Changes in standing crop values were primarily related to stream temperature (r = .6824) and stream discharge (r = .5675). It appeared that as stream discharge decreased, a number of factors, both physical and chemical, operated to influence the phytoplankton community composition and standing crop values. Results of two-way ANOV showed no significant differences among sampling stations for the period of study.

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PHYTOPLANKTON OF THE SANDUSKY RIVER NEAR FREMONT, OHIO[1]

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INTRODUCTION

Although its role is reduced in streams, the phytoplankton may at times contribute significantly to the total riverine productivity and is of economic importance. Pulses of phytoplankton growth have been linked to the imparting of tastes and odors to water supplies, interference with filter beds of water treatment facilities, and detraction of the overall aesthetic quality of bodies of water (Palmer, 1962).

The transitory nature of the phytoplankton is of importance in the monitoring of water quality. Changes in the phytoplankton as it moves with a body of water can reflect short-term variations in the chemical and physical makeup of its environment. Use of phytoplankton in monitoring programs has been largely limited to major waterways of greater economic impact.

Phytoplankton research on the Sandusky River System has been limited to the headwaters near Bucyrus, Ohio (SIRCH, 1972), and the mouth of the river, Sandusky Bay, (Riddle, 1902), Sullivan (1953), and McQuate (1955). The photic zone of the Sandusky River was determined by Verduin (1959). No

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[1] This research was supported by a National Science Foundation Institutional grant to Bowling Green State University, the Bowling Green State University Department of Biological Sciences and the University of Michigan Biological Station.

other data on phytoplankton related to the remaining segments of the Sandusky River have been presented.

The objectives of this study were to 1) provide a taxonomic list of the phytoplankton, 2) determine seasonal trends in the phytoplankton, 3) note spatial differences in the phytoplankton community of the segment of the river near Fremont, Ohio, and 4) relate changes in the phytoplankton with environmental conditions.

MATERIALS AND METHODS

Description of Sampling Area

Selection of four sampling sites was based upon the availabilty of bridges along a twelve kilometer segment of the Sandusky River. The segment of the river that was sampled included that from a point 6.5 km southwest to a point 1.5 km northwest of the city of Fremont, Ohio (Fig. 1). The stations were designated numbers one through four, upstream to downstream. The river flows mostly north in this section over outcrops of the Monroe Limestone alternating with Niagara Limestone and Shale (Schrecongust, 1963). The river is normally sluggish due to an average gradient of less than a meter per kilometer (determined from U.S.G.S. topographic maps). The elevation drops approximately 15 meters over the study area with the most abrupt fall occuring at the Ballville Dam located upstream from station number two.

Station number one, the Tindall Bridge, is located at the junction of Rice Road, a distance of 34.5 km from the mouth of the river, the Sandusky Bay. At this point, the river flows across limestone bedrock and is bounded between rock-cut ledges and is almost entirely free of macrophyte vegetation. The water is fairly shallow most of the year with a slow current. A United States Geological Survey gauging station,

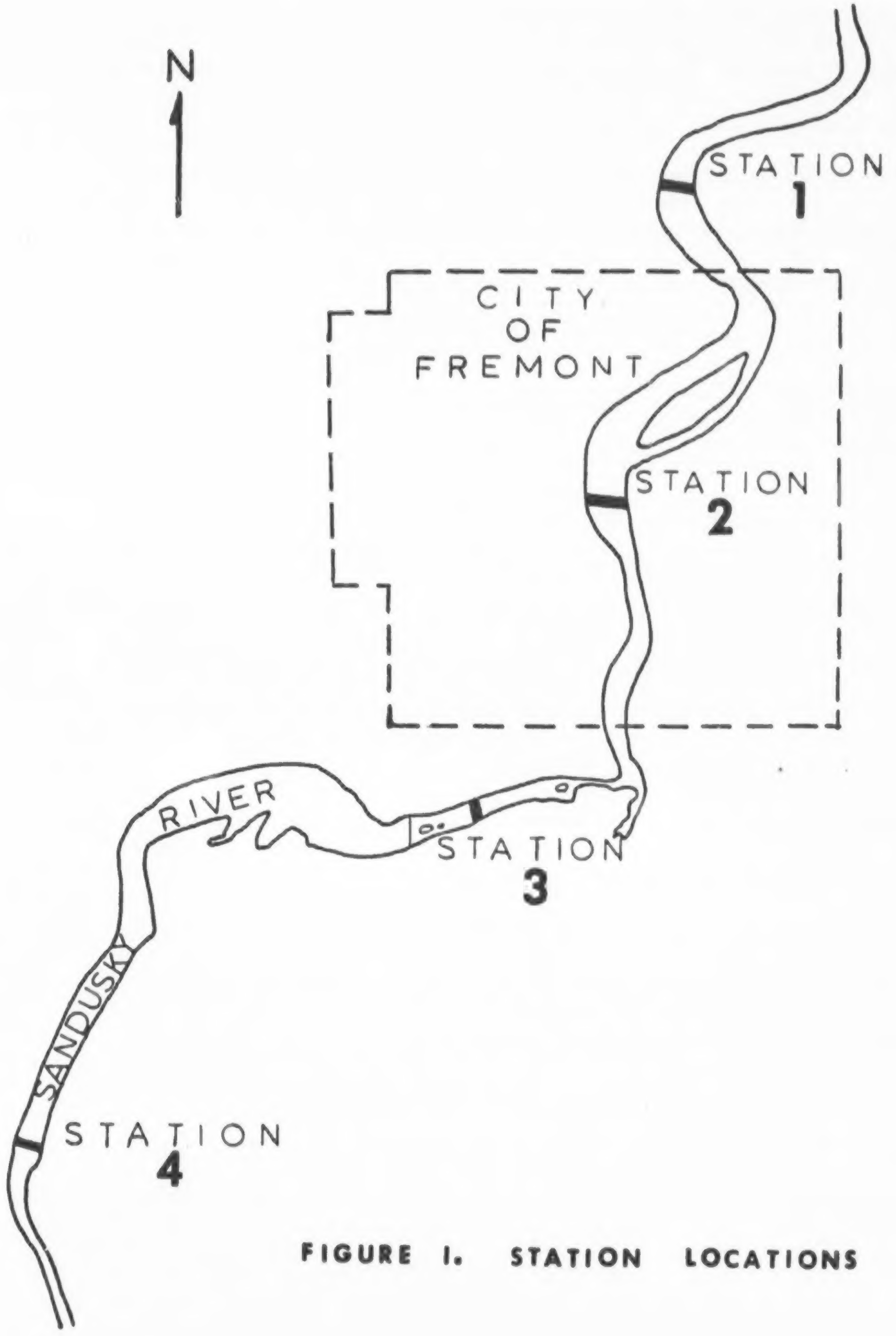
N
STATION 1
CITY OF FREMONT
STATION 2
RIVER
STATION 3
SANDUSKY
STATION 4

FIGURE I. STATION LOCATIONS

located below the bridge, was utilized to assess the flow of the river.

Station two, the Ballville Bridge, is located at the junction of Tiffin Street and the "old" Tiffin Road, approximately 30 km from the mouth of the river. The current is swift as a result of the river's movement over a spillway several hundred meters upstream at the Ballville Dam. As a consequence the water was never ice-covered during the period of study. The substrate is limestone bedrock and the area is almost void of vegetation except for outgrowths of *Cladophora* sp. during periods of cooler water temperature. This station represents an abrupt change in the almost lenthic nature of the impounded stream above the dam. At a point several hundred meters downstream, the river widens slightly as it bends towards the business district of the city of Fremont.

The river at station three, the State Street Bridge, is sluggish and relatively deep. The substrate consists of large rocks and stones. The bridge is located 26 km from the mouth of the river at the point where City Route 20 crosses the river, upstream from the municipal sewage treatment plant. The river is bounded on each side by concrete retaining walls which are a part of the flood protection system for the city of Fremont.

Station number four located next to the Route 19-53-20 by-pass bridge is 22.5 km from the mouth of the river. This station was sampled along the shoreline where the river makes a sharp bend. The bridge was not utilized for safety reasons. The river is sluggish at this point and moderately deep with a substrate of sand and silt. The area is located about one and one-half kilometers below the Fremont municipal sewage treatment plant effluent.

Specimen Preparation and Analysis

Upon returning to the laboratory, 1000 ml granulated cylinders were filled with the samples. Fifteen ml of a standard Lugol's Iodine solution was added to preserve and settle the phytoplankton (Weber, 1968). An equal amount of 40 percent formaldehyde was added to retard bacterial growth. After standing for a period of two weeks to insure complete settling, 90 percent of the supernatant was carefully removed by means of an aspirator. The remaining material, having been concentrated by this process, was mixed to resuspend the phytoplankton, and part of the material was poured into small jars for storage.

The preserved specimens were enumerated in counting chambers according to the technique proposed by Palmer and Maloney (1954). An attempt was made to count 500 cells per sample within the counting chamber. This usually amounted to counting the number of individuals in approximately 20 fields when the phytoplankters were numerous. When organisms were sparse, one half of the Palmer Cell was analyzed. The samples were often concentrated or diluted depending upon the number of individuals or silt content. Three replicate counts were made for each sample.

Individuals were identified to genus at 430X magnification with the exception of diatoms and small green forms. Diatom members of the phytoplankton were merely classified as "centrics" or "pennates." Further identification and quantification of diatoms was made, following the removal of organic content by oxidation, employing Hyrax-mounted slides under the oil immersion objective. Five hundred of the "cleaned" diatom valves were counted to establish the percentage present in the original counts.

The percentages were applied to the original counts to determine the actual number of individuals within a species. Percentage formulation was also applied to other unidentified algal forms but under wet mounts at 1000X magnification, oil immersion.

Since phytoplankton consists of unicellular, colonial, and filamentous algae, units were recorded as follows:

Unicellular Phytoplankters - cell/unit
Colonial Phytoplankters - one colony/unit
Filamentous Phytoplankters - 100 μm/unit

Following quanitification in the chambers, the data was converted into standing crop values in terms of units per milliliter according to the following formula (USEPA, 1973):

$$\text{Units per ml} - \frac{C \times 1000 \text{ mm}^3}{A \times D \times F}$$

where C = number of units counted
A = area of field in mm^2
D = depth in a field in mm
F = number of fields counted

Physical and Chemical Determinations

Analysis of water chemistry was concurrently determined biweekly throughout the period of study employing a Hach DR-EL Colorimeter. The parameters recorded included alkalinity, hardness, nitrate nitrogen, nitrite nitrogen, orthophosphate, silica, transparency, and turbidity. The pH values of the samples were determined by means of a Corning Electric pH Meter. Dissolved oxygen and temperature were determined in the field along with discharge values as previously mentioned.

RESULTS

PHYSICAL AND CHEMICAL RESULTS

Water Temperature

Temperature of river water from the study area ranged from 0° C. on several occasions to 20.5° C. (station four only) on March 26, 1974 samplings. The water temperature generally reflected ambient air temperatures. The average water temperature for the period of study was approximately 8° C.

Three sampling stations were totally or partially ice-covered on four occasions during the period December 23, 1973 through February 17, 1974. Station one was partially ice-covered during that period but had open water at mid-channel. Station two was never ice-covered. Stations three and four were completely frozen over during this period with a maximum thickness of five inches on January 6, 1974.

Discharge

River discharge values, as measured by U.S.G.S. gauging equipment at station one, ranged from 60 cubic feet per second (c.f.s.) on November 28, 1973 to a high of 13,767 c.f.s. following the mid-winter thaw on January 20, 1974. Discharge values of 1,000 c.f.s. occurred from December 23, 1974 through April 28, 1974. Autumn and late spring discharges were generally very low. The average discharge of the river during the study period was 2,341 c.f.s.

Turbidity

Turbidity values ranged from 0 Jackson Turbidity Units (J.T.U.) to 410 J.T.U. Higher turbidity readings were generally associated with increased discharge. A reading of 410 J.T.U. was recorded as the river crested at flood stage on January 20, 1974. The lowest turbidity value, 0 J.T.U. was recorded one month later. The average turbidity reading for the river during the study period was approximately 95 J.T.U. Variance in turbidity determinations were noted among sampling stations, but did not appear to be appreciably different.

Percent Light Transmission

Levels of light transmission for smaples collected at the river surface varied from 37 percent to 97 percent. Light transmission was seriously reduced during periods of high discharge and turbidity. The average light transmission for samples collected during the study was around 83 percent.

Hydrogen Ion Concentration

The pH for the segment of the river studied varied from 7.0 to 8.45 with an average of 7.9. The hydrogen ion concentration varied seasonally and did not appear to be a function of the discharge.

Alkalinity

Alkalinity values ranged from 85 parts per million (ppm) at station three on March 7, 1974 to 215 ppm at stations two and four and November 25, 1973. The alkalinity values, like pH, showed a seasonal variance but did not appear to be directly related to stream discharge. During the period of study the samples had an average alkalinity of 166 ppm.

Hardness

An association between discharge and hardness was noted during the period of study. The lowest value, 55 ppm, was recorded at station two on January 20, 1974 during flood stage. A peak of 370 ppm was noted during low flow at stations one and four on November 25, 1973. An average of 272 ppm was obtained for the 8 month study.

Nitrate Nitrogen

Nitrate nitrogen values ranged from a low of 3.5 ppm on May 12, 1974 at station one to a high of 162.8 at station four on October 28, 1973. The nitrate nitrogen values were generally much higher in the autumn samplings than those in the spring samplings. Spring phytoplankton maxima were associated with the lowest nitrate nitrogen values.

Nitrite Nitrogen

Nitrite nitrogen determinations ranged from 0.01 ppm on January 20, 1974 at stations two, three, and four to a high of 0.36 ppm on March 3, 1974. Nitrite nitrogen values were consistently higher at station four which was located downstream from the municipal sewage treatment plant. The differences appeared to be appreciably different with the exception of periods of higher river flow.

Orthophosphate

Values for orthophosphate were noticeably higher at station four on most sampling dates. Values for orthophosphate were lower during periods of higher phytoplankton productivity. The average orthophosphate was 0.5 ppm.

Silica

Silica levels were sufficiently high at all times to support phytoplankton standing crops. Station two recorded a reading of 17.5 on December 23, 1973. Lower silica levels were noted during periods of higher phytoplankton production. The average silica level for the eight month study was 7.61 ppm.

Dissolved oxygen

Dissolved oxygen ranged from 5 ppm to saturation. Dissolved oxygen at station four located below the municipal sewage treatment plant was consistently lower than upstream stations during low flow periods. Dissolved oxygen determinations showed little interstation variation at other sampling sites.

BIOLOGICAL RESULTS

A total of 265 algal taxa were identified during the course of the study. The list included 206 diatoms, 43 green algae, 2 chrysophytes, 8 blue-greens, 4 euglenoids, and 2 dinoflagellates (Appendix).

Diatoms dominated the phytoplankton community throughout the period of study, ranging from 78 percent to 93 percent of the phytoplankton. Diatom taxa commonly occurring included the centric diatoms *Cyclotella atomus, C. meneghiniana, C. pseudostelligera, Melosira granulata, M. varians, Microsiphona potamos, Stephanodiscus hantzchii, S. invisitatus,* and *Thalassiosira pseudonana*. Pennate diatoms included *Cymatopleura solea, Fragilaria vaucheriae, Gomphonema olivaceum, G. parvulum, Gyrosigma obtusatum, Navicula cryptocephala, N. cryptocephala* var. *intermedia, N. cryptocephala* var. *veneta, N. lanceolata, N. tripunctata, Nitzschia apiculata, N. dissipata,* and *Surirella ovata*.

Green algae were also important in the phytoplankton of the Sandusky River comprising between 5.1 percent and 16.4 percent. *Ankistrodesmus convolutus, A. falcatus,* two unidentified species of *Chlamydomonas, Dictyosphaerium pulchellum, Scenedesmus quadricauda,* and unidentified coccoid green algae commonly comprised this portion of the phytoplankton. Coccoid greens were not able to be identified, and may have represented fragments of colonial greens, reproductive stages, or other forms requiring culture techniques to complete identification.

Euglenoid algae represented by *Euglena* sp. and two species of *Trachel-*

monas were present in low numbers throughout the study. *Dactylococcopsis* and sp. *Oscillatoria* sp. were the only blue-green algae showing regular occurrence in the phytoplankton, but were present in low numbers. Occurence of Chrysophyceae was rare and never high in number.

Spatial Variation

Variations in the total phytoplankton standing crop values among the four sampling stations were determined to be not significant (two-way analysis of variance $p<0.05$) for the study period. Similar conclusions were realized following two-way analysis of variation statistics for major algal groups and dominant taxa.

Seasonal Variation

Simple linear regression analysis indicated a strong relationship between mean stream temperature and phytoplankton standing crop values. The relationship was found to be significant at $P<0.01$. This relationship is presented in figure 2.

Autumnal and spring maxima were observed during periods of low river discharge and water temperatures. Lowest standing crop values were recorded during the period December 9, 1973 through April 14, 1974 when temperatures were low and stream discharge high. Average plankton cell counts ranged from a low of 101 cells per milliliter on January 6, 1974 to a high of 83,063 cells per milliliter in the spring samples on May 12, 1974 (Table 1).

Figure 3 shows the relationship between stream discharge and standing crop values. The mean discharge value for the period two days prior to sampling through the day of sampling regresses upon the standing crop values showed a significant inverse relationship ($r = -.5675$). A student

TABLE 4

Mean Standing Crop Values and Percent Abundances of Phytoplankton Collected at Four Sampling Stations along the Sandusky River at Fremont, Ohio, October 14, 1973 through May 26, 1974.

Date	Total Phytoplankton No./ml.	Bacillariophyceae No./ml.	Bacillariophyceae %	Chlorophyceae No./ml.	Chlorophyceae %	Chrysophyceae No./ml.	Chrysophyceae %	Dinophyceae No./ml.	Dinophyceae %	Euglenophyceae No./ml.	Euglenophyceae %	Myxophyceae No./ml.	Myxophyceae %
October 14, 1973	73798	64486	87.38	8644	11.71			34	0.05	634	0.86		
October 28, 1973	36725	32461	88.39	4151	11.30			15	0.04	98	0.27		
November 11, 1973	36552	33307	91.12	3237	8.86					8	0.02		
November 25, 1973	36949	33054	89.46	3805	10.30					7	0.02	83	0.22
December 9, 1973	129	120	93.02	7	5.43					1	0.78	1	0.77
December 23, 1973	292	227	77.[illegible]4	15	5.14					1	0.34	49	16.78
January 6, 1974	101	89	88.12	9	8.91	1	0.99			1	0.99	1	0.99
January 20, 1974	654	557	85.17	69	10.55					18	2.75	10	1.53
February 3, 1974	201	181	90.05	16	7.96					3	1.49	1	0.50
February 17, 1974	189	161	85.19	25	13.23	1	0.52			1	0.65	1	0.53
March 3, 1974	338	281	83.14	37	10.95	1	0.30			3	0.89	16	4.73
March 17, 1974	326	289	88.65	33	10.12	2	0.61			1	0.31	1	0.31
March 31, 1974	337	312	92.58	23	6.82					1	0.30	1	0.30
April 14, 1974	427	394	92.27	23	5.39	1	0.23			6	1.41	3	0.70
April 28, 1974	40556	36924	91.04	3579	8.82			12	0.03	21	0.05	20	0.05
May 12, 1974	83063	76743	92.39	5154	6.20	325	0.39			841	1.01		
May 26, 1974	22749	18990	83.48	3741	16.44					13	0.06	5	0.02
Mean	19611	17563	89.56	1916	9.77	19	0.10	4	0.02	98	0.50	11	0.05

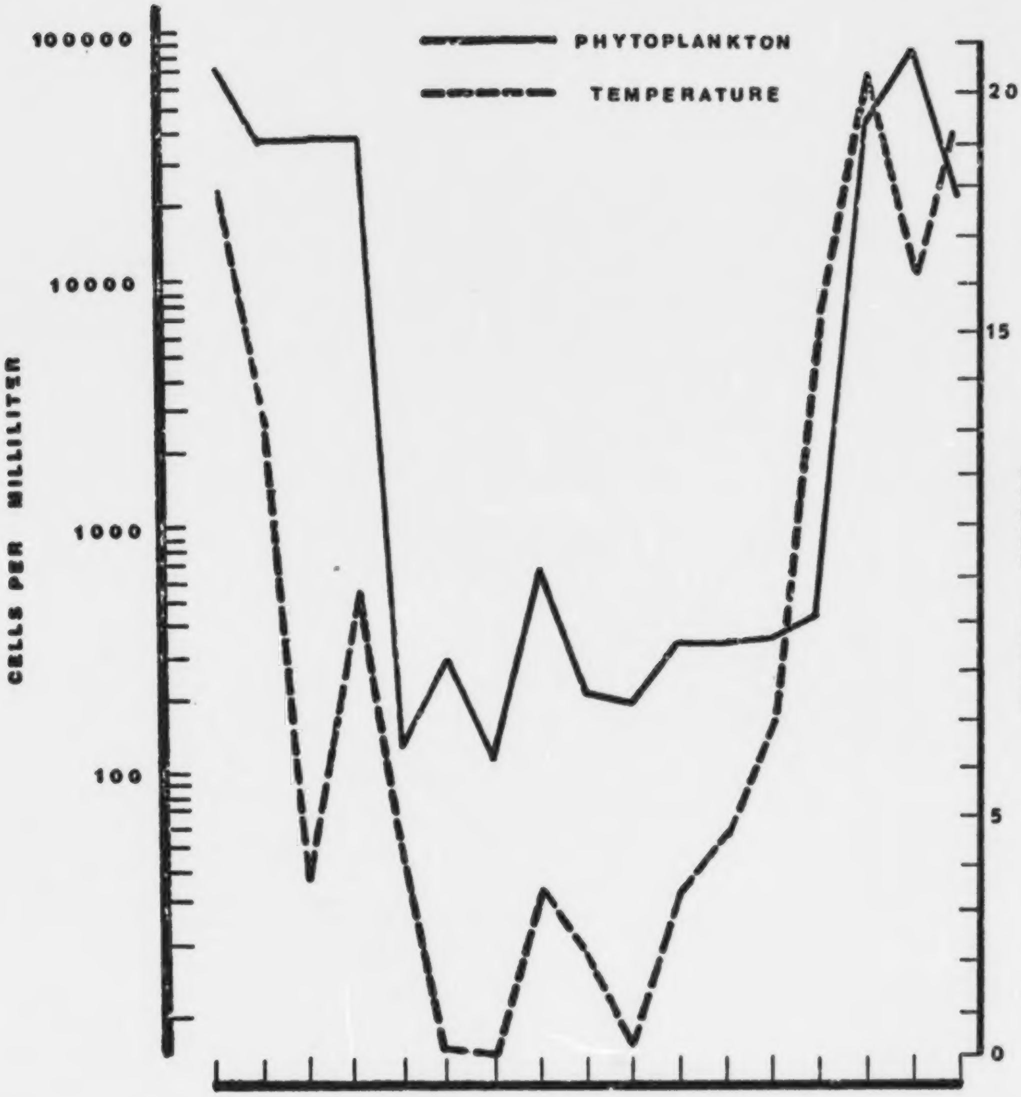

FIGURE 2. SEMI-LOGARITHMIC PLOT OF THE AVERAGE PHYTOPLANKTON STANDING CROP VALUES, AND STREAM TEMPERATURE, OCTOBER 14, 1973 THROUGH MAY 26, 1974.

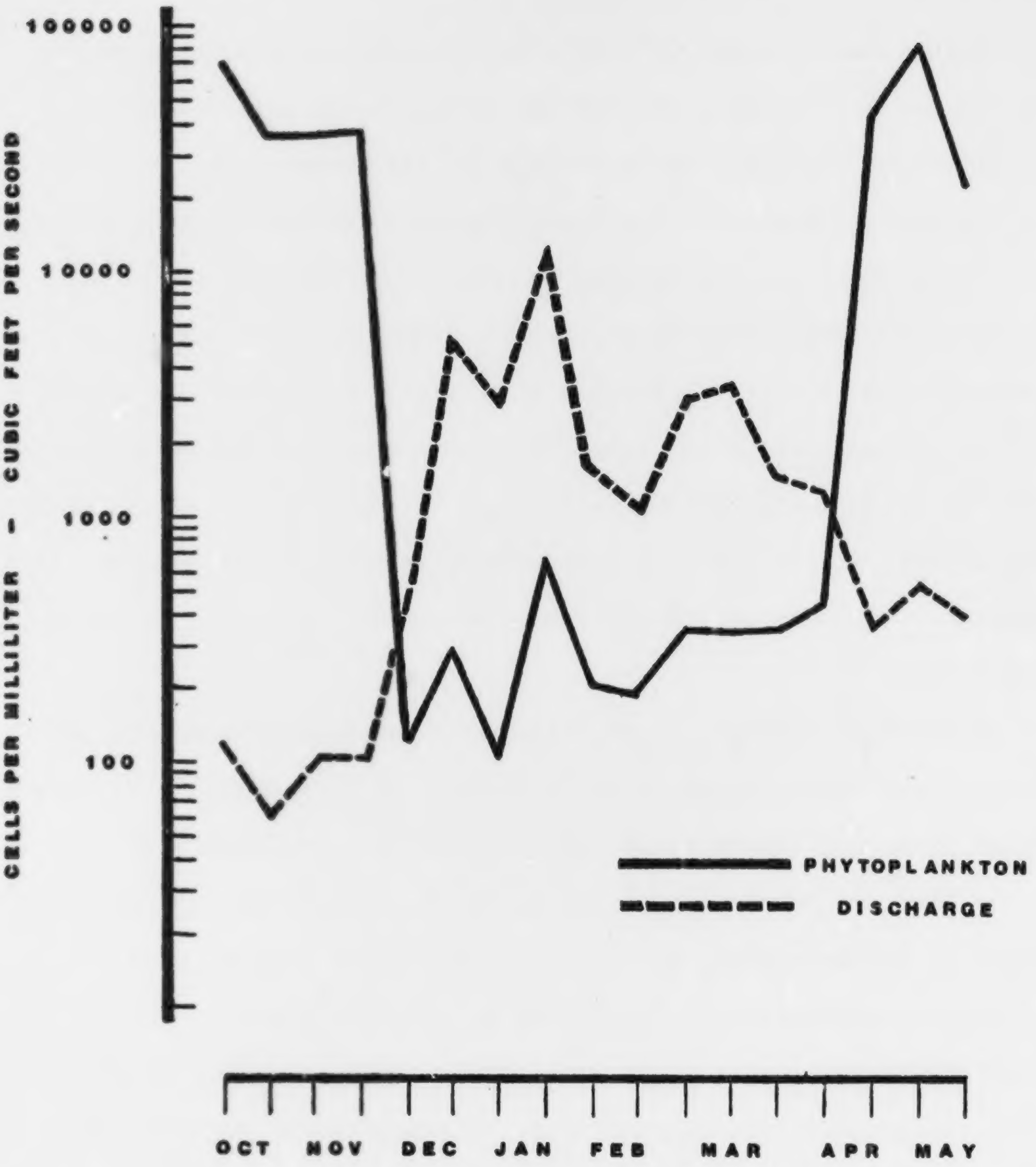

FIGURE 3. SEMI-LOGARITHMIC PLOTS OF THE AVERAGE PHYTOPLANKTON STANDING CROP VALUES AND STREAM DISCHARGE, OCTOBER 14, 1973 THROUGH MAY 26, 1974.

t-test applied to this relationship shows significance at P<0.05, but not at P<0.01.

Autumn samples contained high numbers of centric diatoms, composing 87 percent to 91 percent of the total community. *Cyclotella atomus* dominated the phytoplankton on October 14, 1973 ranging from 35,936 cells per milliliter ar station four to 63,113 cells per milliliter at station one. Although *C. atomus* remained in high number, its dominance tended to decline through the November 25, 1973 samples. *Cyclotella meneghiniana* co-dominated, varying considerably from station to station; its abundance in the community was fairly constant. Another centric diatom, *Microsiphona potamos* was also abundant during this period. *Stephanodiscus invisitatus* was present in high number in the November 11, 1973 and November 25, 1973 samples. These two sampling dates followed peiods of declining stream discharge.

Other algae abundant in the fall sample included *Chlamydomonas* sp. 2 which was quite numerous at three stations on October 14, 1973. Coccoid green forms were common to all stations throughout the autumn.

A dramatic decrease in the phytoplankton standing crop values was noted in the December 9, 1973 samples. The sudden drop followed the seasonal temperature decline and increasing stream discharge levels. One hundred and twenty nine cells per milliliter were counted on December 9, 1973. Standing crop values remained low through April 14, 1974. The stream discharge remained high while water temperatures remained low.

Although cell counts dropped, *Cyclotella atomus* and *C. meneghiniana* continued to dominate the winter phytoplankton. A noticeable increase in the presence of tychoplanktonic forms was noted in the winter samples.

Taxa normally found in the periphyton constituted the bulk of the organisms identified from the phytoplankton sampled during that time.

Cyclotella meneghiniana was found at nearly every station throughout the winter months. In most samples, it was one of the dominant forms. *Microsiphona potamos*, present in samples through December 23, 1973 did not appear again until April 14, 1974. The early winter samples were dominated by *Navicula cryptocephala*, *Nitzschia dissipata*, and *Surirella ovata* in addition to *C. meneghiniana*. Some stations showed some differences with *Navicula tripunctata*, *Fragilaria vaucheriae*, *Rhoicosphenia curvata*, *Cymatopleura solea*, *Gyrosigma obtusatum*, *Oscillatoria* sp., and *Chlamydomonas* sp. increasing in abundance at certain times.

In early spring, *Gomphonema*, *parvulum* and *Stepanodiscus hantzschii* began to comprise a large portion of the phytoplankton. Spring increase was first noted with April 28, 1974 samples. The community was dominated by the centric diatoms *Stephanodsicus hantzschii* and *S. invisitatus*. A decrease in stream discharge and increased temperatures accompanied the spring pulse. Many of the tychoplanktonic forms so common in winter samples were absent or at least masked by the large occurrence of centric diatoms. Other algal forms, green algae in particular, were common.

Highest standing crop values for the spring were recorded in the May 12, 1974 samples. In addition to high numbers of *Stephanodiscus hantzschii*, a large pulse of the centric diatom *Microsiphona potamos* were recorded. *Cyclotella atomus*, *C. meneghiniana*, and *Stephanodiscus invisitatus* were very high in number. Although the total phytoplankton standing crop had declined by May 26, 1974, the community make-up remained similar to the previous sample.

DISCUSSION

Responses of the phytoplankton community to varying environmental conditions as it passed through the segment of the Sandusky River near Fremont were anticipated. Although some variance in standing crop values at the four sampling stations was noted, no significant differences were recorded for the period of the study.

The source of individuals found in the stream plankton has been linked to areas of reduced stream flow. Krieger in Fjerdinstad (1950) gave four sources of phytoplankton in rivers: 1) regions in which the river rises, 2) ponds, 3) lakes, and 4) canals and tributaries. Butcher (1932) added that a fifth source should be included in this list, the river bed. Reinhard (1931) concluded that the environment allowing the greatest time for the development of the plankton will produce the greatest crop. Yet, the impoundment of water behind the Ballville Dam apparently did not allow for reproduction of phytoplankton to sufficiently alter standing crop values at downstream stations. Furthermore, passage of the community over the spillway apparently was not physically damaging. Lauterborn (1910) indicated that *Fragilaria, Cyclotella,* and colonies of *Asterionella* have passed over larger falls without damage.

Of interest was the lack of expected response of the phytoplankton to higher nuturient levels in areas below the effluent of the city sewage treatment facility during periods of reduced flow. Though the final sampling station was more than a kilometer from the effluent, a response may not have been realized until further downstream. It is also possible that nutrients were already at a high level, and further increases in the phytoplankton may have been limited by other physical or chemical factors, despite increases in the areas below the effluent. Only macronutrients were monitored during this study. Thus a trace element could have limited an increase in the phytoplankton with heightened macronutrient loads. High silt load of the Sandusky River may have played a role in the extent of standing crop production by reducing the amount of light available to the phytoplankton.

Most noticeable in the study was that of seasonable change in the phytoplankton community. Both autumnal and vernal maxima were noted, separated by a period when euplanktonic forms were minimal. Many investigators have noted similar occurrences (Blum, 1956). River discharge appeared to be a governing factor in the seasonal periodicity. Standing crop values significantly reflected changes in the discharge of the river. Egborge (1974) found a significant negative correlation between standing crop and stream velocity. Swale (1964) pointed out stream flow as the dominant physical factor affecting planktonic life in streams. An indication of the time necessary for a response by the phytoplankton community was demonstrated by the significant inverse relationship between standing crop values and stream discharge. The discharge values for the period two days prior to sampling through the day of sampling closely paralleled changes in phytoplankton numbers. Furthermore, since the regression was significant at $P<0.05$ and not at $P<0.01$, the input of other environmental factors is suggested.

Sudden changes in phytoplankton numbers occurred during periods of changing temperature and light, both in duration and intensity. Intensity and duration of light are important in the process of photosynthesis in phytoplankton. Photosynthesis, as well as other physiological processes, is temperature dependent. Determination of the effects of changing temperature and light on phytoplankton growth is difficult since these parameters vary simultaneously. The strong relationship found between stream temperature and standing crop values may be a function of concurrent high light intensity and duration.

Water temperature and light are influenced by stream discharge. Silt associated with increased discharge reduces the light available to phytoplankton. Ellis (1936) found light intensity to be severly reduced in the Mississippi River as a result of silt. He also noted that silt altered the rate of temperature change. Berner (1951) related changes in several parameters as a result of turbidity in the Missouri River. With increased turbidity, Berner noted a decrease in dissolved oxygen and an increase in temperature. The Sandusky River, as a smaller stream, is subject to sharper fluctuations in discharge than larger streams. Thus, discharge is an important factor affecting phytoplankton in the Sandusky River.

Seasonal phytoplankton standing crop numbers from samples collected from the Sandusky River in the Fremont, Ohio area are similar to those reported by Weber and Moore (1967) for the little Miami River (Ohio). Williams (1962), however, reported standing crop values for larger rivers in the Midwest that were seasonally lower than those from the Sandusky River samples. It should be emphasized that the results of this study pertain to surface samples only. Verduin (1959) has shown the photic zone in the Sandusky River to be limited to 0.5 meter beneath the surface.

It should be noted that standing crop values present only relative indications of the productivity of the phytoplankton community (Lund, 1965). The bulk of the community is composed of nannoplankters, plankton of 20 μm (micrometers) or smaller. Thus, although the standing crop values are high, the total biomass may be low compared to other communites. Further research will be needed to assess the contribution of phytoplankton to the total primary production of the Sandusky River.

APPENDIX

Cumulative List of Taxa Found in Phytoplankton Samples Collected from the Sandusky River at Fremont, Ohio, October 14, 1973 through May 26, 1974.

Bacillariophyceae

Achnanthes *affinis* Grun. var. *affinis*

Achnanthes *clevei* Grun. var. *clevei*

Achnanthes *exigua* Grun. var. *exigua*

Achnanthes *hungarica* (Grun.) Grun. var. *hungarica*

Achnanthes *lanceolata* Bréb. var. *lanceolata*

Achnanthes *lanceolata* var. *dubia* Grun.

Achnanthes *minutissima* Kütz. var. *minutissima*

Achnanthes *pinnata* Hust. var. *pinnata*

Achnanthes sp.

Amphora *delicatissima* Krasske var. *delicatissima*

Amphora *normani* Rabh. var. *normani*

Amphora *ovalis* Kütz. var. *ovalis*

Amphora *ovalis* var. *pediculus* Kütz.

Asterionella *formosa* Hass. var. *formosa*

Bacillaria *paradoxa* var. *tumidula* Grun.

Caloneis *bacillum* (Grun.) Cl. var. *bacillum*

Caloneis *hyalina* Hust. var. *hyalina*

Cocconeis *fluviatilus* Wallace var. *fluviatilus*

Cocconeis *pediculus* Ehr. var. *pediculus*

Cocconeis *placentula* var. *euglypta* (Ehr.) Cl.

Cocconeis *placentula* var. *lineata* (Ehr.) V.H.

Cyclotella *atomus* Hust. var. *atomus*

Cyclotella meneghiniana Kütz. var. *meneghiniana*
Cyclotella pseudostelligera Hust. var. *pseudostelligera*
Cyclotella stelligera Cl. et Grun. var. *stelligera*
Cyclotella sp.
Cymatopleura solea (Bréb.) W. Sm. var. *solea*
Cymbella prostrata (Berk.) Cl. var. *prostrata*
Cymbella sinuata Greg. var. *sinuata*
Cymbella tumida (Bréb.) V.H. var. *tumida*
Cymbella ventricosa Kütz. var. *ventricosa*
Cymbella sp.
Diatoma tenue var. *elongatum* Lyngb.
Diatoma vulgare var. *breve* Grun.
Diatoma vulgare Bory var. *vulgare*
Diatoma sp.
Diploneis puella (Schum.) Cl. var. *puella*
Epithemia sp.
Eunotia curvata (Kütz.) Lagerst. var. *curvata*
Eunotia pectinalis (O.F.Müll?) Rabh. var. *pectinalis*
Eunotia sp.
Fragilaria capucina Desm. var. *capucina*
Fragilaria capucina var. *mesolepta* Rabh.
Fragilaria construens (Ehr.) Grun. var. *construens*
Fragilaria construens var. *pumilla* Grun.
Fragilaria construens var. *venter* (Ehr.) Grun.
Fragilaria crotonensis Kitton var. *crotonensis*
Fragilaria crotonensis var. *oregona* Sov.

Fragilaria *leptostauron* (Ehr.) Hust. var. *leptostauron*

Fragilaria *pinnata* Ehr. var. *pinnata*

Fragilaria *vaucheriae* (Kütz.) Peters. var. *vaucheriae*

Fragilaria *virescens* var. *capitata* Øst.

Fragilaria *virescens* Ralfs. var. *virescens*

Fragilaria spp.

Frustulia *rhomboides* (Ehr.) Det. var. *rhomboides*

Frustulia *vulgaris* (Thwaites) Det. var. *vulgaris*

Gomphonema *abbreviatum* (Ag.) Kütz. var. *abbreviatum*

Gomphonema *acuminatum* Ehr. var. *acuminatum*

Gomphonema *acuminatum* var. *coronata* (Ehr.) W. Sm.

Gomphonema *angustatum* (Kütz.) Rabh. var. *angustatum*

Gomphonema *constrictum* Ehr. var. *constrictum*

Gomphonema *gracile* Ehr. var. *gracile*

Gomphonema *insigne* Greg. var. *insigne*

Gomphonema *lanceolata* var. *insignis* (Greg.) Cl.

Gomphonema *longiceps* Ehr. var. *longiceps*

Gomphonema *montanum* var. *media* Grun.

Gomphonema *olivaceum* (Lyng.) Kütz. var. *olivaceum*

Gomphonema *parvulum* (Kütz.) Grun. var. *parvulum*

Gomphonema *sphaerophorum* Ehr. var. *sphaerophorum*

Gomphonema *turris* Ehr. var. *turris*

Gomphonema spp.

Gyrosigma *attenuatum* (Kütz.) Rabh. var. *attenuatum*

Gyrosigma *obtusatum* (Sulliv. and Wormley) Boyer var. *obtusatum*

Gyrosigma *scalproides* (Rabh.) Cl. var. *scalproides*

Gyrosigma *spencerii* var. *curvula* (Grun.) Reim.

Gyrosigma *spencerii* (Quek.) Griff and Henfr. var. *spencerii*

Gyrosigma *wormleyi* (Sulliv.) Boyer var. *wormleyi*

Hantzschia *amphioxys* (Ehr.) Grun. var. *amphioxys*

Melosira *ambigua* (Grun.) O. Müll. var. *ambigua*

Melosira *granulata* (Ehr.) Ralfs var. *granulata*

Melosira *varians* Ag. var. *varians*

Meridion *circulare* (Grev.) Ag. var. *circulare*

Microsiphona *potamos* Weber var. *potamos*

Navicula *accomoda* Hust. var. *accomoda*

Navicula *bacillum* Ehr. var. *bacillum*

Navicula *capitata* Ehr. var. *capitata*

Navicula *cincta* (Ehr.) Ralfs var. *cincta*

Navicula *cryptocephala* Kütz. var. *cryptocephala*

Navicula *cryptocephala* var. *intermedia* Grun.

Navicula *cryptocephala* var. *veneta* (Kütz.) Rabh.

Navicula *cuspidata* (Kütz.) Kütz. var. *cuspidata*

Navicula *decussis* Øst. var. *decussis*

Navicula *elginensis* (Greg.) Ralfs. var. *elginensis*

Navicula *exigua* Greg. ex Grun. var. *exigua*

Navicula *gastrum* (Ehr.) Kütz. var. *gastrum*

Navicula *gottlandica* Grun. var. *gottlandica*

Navicula *graciloides* A. Mayer var. *graciloides*

Navicula *gregaria* Donk. var. *gregaria*

Navicula *halophila* (Grun.) Cl. var. *halophila*

Navicula *heufleri* Grun. var. *heufleri*

Navicula *heufleri* var. *leptocephala* (Bréb. ex. Grun.) Patr. comb.

Navicula *hustedtii* Krasske var. *hustedtii*

Navicula *integra* (W. Sm.) Ralfs. var. *integra*

Navicula *lanceolata* (Ag.) Kütz. var. *lanceolata*

Navicula *longistris* Hust. var. *longistris*?

Navicula *menisculus* var. *upsaliensis* (Grun.) Grun.

Navicula *minima* Grun. var. *minima*

Navicula *mutica* Kütz. var. *mutica*

Navicula *mutica* var. *stigma* Patr.

Navicula *mutica* var. *undulata* (Hilse) Grun.

Navicula *pelliculosa* (Bréb. ex. Kütz.) Hilse var. *pelliculosa*

Navicula *pseudoreinhardtii* Patr. var. *pseudoreinhardtii*

Navicula *pupula* var. *capitata* Skv. and Meyer

Navicula *pupula* var. *mutica* (Krasske) Hust.

Navicula *pupula* Kütz. var. *pupula*

Navicula *pygmaea* Kütz. var. pugmaea

Navicula *radiosa* var. *parva* Wallace

Navicula *radiosa* Kütz. var. *radiosa*

Navicula *reinhardtii* (Grun.) Grun. var. *reinhardtii*

Navicula *rhynchocephala* var. *amphiceros* (Kütz) Grun

Navicula *rhynchocephala* Kütz. var. *rhynchocephala*

Navicula *salinarum* Grun. var. *salinarum*

Navicula *savannahiana* Patr. var. *savannahiana*

Navicula *schroeteri* Patr. var. *escambia*

Navicula *secura* Patr. var. *secura*

Navicula *symmetrica* Patr. var. *symmetrica*

Navicula tenera Hust. var. *tenera*

Navicula tripunctata var. *schizonemoides* (V.H.) Patr.

Navicula tripunctata (O.F.Müll.) Bory var. *tripunctata*

Navicula viridula var. *avenacea* (Bréb. ex Grun.) V.H.

Navicula viridula var. *linearis* Hust.

Navicula viridula Kütz. emend V.H. var. *viridula*

Navicula spp.

Neidium bisulcatum (Lagerst.) Cl. var. *bisulcatum*

Nitzschia acicularis W. Sm. var. *acicularis*

Nitzschia acuta Hantzsch var. *acuta*

Nitzschia amphibia Grun. var. *amphibia*

Nitzschia angustata (W. Sm.) Grun. var. *angustata*

Nitzschia apiculata (Greg.) Grun. var. *apiculata*

Nitzschia capitellata Hust. var. *capitellata*

Nitzschia communis Rabh. var. *communis*

Nitzschia dissipata (Kütz.) Grun. var. *dissipata*

Nitzschia fasiculata Grun. var. *fasiculata*

Nitzschia flexa Schumann var. *flexa*

Nitzschia fonticola Grun. var. *fonticola*

Nitzschia frustulum Kütz. var. *frustulum*

Nitzschia hungarica Grun. var. *hungarica*

Nitzschia linearis W. Sm. var. *linearis*

Nitzschia obtusa W. Sm. var. *obtusa*

Nitzschia palea (Kütz.) W. Sm. var. *palea*

Nitzschia paleacea Grun. var. *paleacea*

Nitzschia parvula Lewis var. *parvula*

Nitzschia *punctata* (W. Sm.) Grun. var. *punctata*

Nitzschia *recta* Hantzsch var. *recta*

Nitzschia *romana* Grun. var. *romana*

Nitzschia *sigma* (Kütz.) W. Sm. var. *sigma*

Nitzschia *sigmoidea* (Ehr.) W. Sm. var. *sigmoidea*

Nitzschia *thermalis* Kütz. var. *thermalis*

Nitzschia *tryblionella* var. *levidensis* (W. Sm.) Grun.

Nitzschia *tryblionella* Hantzsch var. *tryblionella*

Nitzschia *tryblionella* var. *victoriae* Grun.

Nitzschia *vermicularis* (Kütz.) Grun. var. *vermicularis*

Nitzschia *vitrea* Norman var. *vitrea*

Nitzschia *vivax* W. Sm. var. *vivax*

Nitzschia spp.

Opephora *martyi* Herib. var. *martyi*

Pinnularia *borealis* Ehr. var. *borealis*

Pinnularia *brebissonii* var. *dimunuta* (Grun.) Cl.

Pinnularia spp.

Rhoicosphenia *curvata* (Kütz.) Grun. ex Rabh. var. *curvata*

Stauroneis *anceps* Ehr. var. *anceps*

Stauroneis *anceps* f. *gracilis* Rabh.

Stauroneis *ignorata* Hust. var. *ignorata*

Stauroneis *smithii* Grun. var. *smithii*

Stauroneis sp.

Stephanodiscus *astraea* var *mintula* (Kütz) Grun.

Stephanodiscus *hantzschii* Grun. var *hantzschii*

Steaphanodiscus *invisitatus* Hohn and Hellerman var. *invisitatus*

Stephanodiscus sp.

Surirella angustata Kütz. var. *angustata*

Surirella delicatissima Lewis var. *delicatissima*

Surirella ovalis (Bréb.) var. *ovalis*

Surirella ovata var. *crumena* Breb.

Surirella ovata var. *pinnata* W. Sm.

Surirella ovata var. *salina* W. Sm.

Surirella robusta Ehr. var. *robusta*

Surirella sp.

Synedra acus Kütz. var. *acus*

Synedra amphicephala Kütz. var. *amphicephala*

Synedra delicatissima W. Sm. var. *delicatissima*

Synedra fasiculata (Ag.) Kütz. var. *fasiculata*

Synedra incisa Boyer var. *incisa*

Synedra parasitica (W. Sm.) Hust. var. *parasitica*

Synedra parasitica var. *subconstricta* (Grun.) Hust.

Synedra pulchella Ralf. ex. Kütz. var. *pulchella*

Synedra radians Kütz. var. *radians*

Synedra rumpens var. *familaris* (Kütz.) Hust.

Synedra rumpens var. *fragilariodes* Grun.

Synedra rumpens var. *meneghiniana* Grun.

Synedra rumpens Kütz. var. *rumpens*

Synedra ulna (Nitz.) Ehr. var. *ulna*

Synedra ulna var. *danica* (Kütz.) V.H.

Synedra spp.

Tabellaria flocculosa (Roth) Kütz. var. *flocculosa*

Thalassiosira fluviatilus Hust. var. *fluviatilus*

Thalassiosira pseudonana (Hust.) Hasle and Heimdal var. *pseudonana*

Chlorophyceae

Actinastrum hantzschii Lagerheim

Ankistrodesmus convolutus Corda

Ankistrodesmus falcatus (Corda) Ralfs.

Carteria sp.

Characium sp.

Chlamydomonas sp. 1

Chlamydomonas sp. 2

Chlamydomonas sp. 3

Chlamydomonas sp. 4

Chlorella vulgaris Beyerinck

Chlorella sp.

Closteriopsis longissima Lemmerman

Coelastrum sphaericum Naegeli

Cosmarium sp.

Crucigenia apiculata (Lemm.) Schmidle var. *truncata* (G.M.Smith) Ahlstrom and Tiffany

Crucigenia quadrata Morren

Dictyosphaerium pulchellum Wood

Dictyosphaerium sp.

Golenkinia radiata (Chod.) Wille

Kirchneriella lunaris (Kirch)

Lagerheimia sp.

Micractinium pusillum Fresenius

Micractinium sp.

Oocystis borgei Snow

Oocystis sp.

Pandorina morum (Muell.) Bory

Pediastrum duplex Meyer

Pediastrum tetras Ralfs

Scenedesmus abundans (Kirch.) Chodat.

Scenedesmus acuminatus (Lagerh.) Chodat.

Scenedesmus anomolus (G.M.Smith) Ahlstrom and Tiffany

Scenedesmus bijuga (Turp.) Lagerheim

Scenedesmus dimorphus (Turp.) Kuetzing

Scenedesmus opoliensis P. Richter

Scenedesmus quadricauda (Turp.) de Brebisson

Scenedesmus quadricauda (Turp.) de Brebisson var. *alternans* G. M. Smith

Scenedesmus sp.

Selenastrum sp.

Sphaerocystis schroeteri Chodat.

Tetraedron sp.

Tetrastrum heterocanthum (Nordst.) Chodat.

Tetrastrum staurogeniaeformae (Schroeder) Lemmermann

Tetrastrum sp.

Chrysophyceae

Dinobryon sertularia Ehr.

Dinobryon sp.

Dinophyceae

Gymnodinium sp.

Peridinium sp.

Euglenophyceae

Euglena sp.

Phacus sp.

Trachelomonas sp. 1

Trachelomonas sp. 2

Myxophyceae

Anabaena sp.

Chroococcus sp.

Dactylococcopsis sp.

Lyngbya sp.

Merismoepedia sp.

Microcystis sp.

Oscillatoria sp.

Raphidiopsis curvata Fritsch and Rich

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ABSTRACT

A COMPARISON OF THE WINTER DIATOM OF THE SANDUSKY RIVER AND TYMOCHTEE CREEK

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Periphyton grab samples were collected from fourteen stations in the Sandusky River on February 15 and Tymochtee Creek on March 6, 1975. The samples were cleaned employing hydrogen peroxide-potassium dichromate to enable the classification of the diatom taxa present.

The relative abundance of each diatom taxa was determined by randomly counting 500 valves from each sample. Relative abundance of a diatom taxon was recorded as abundant if that taxon represented 20% or more of the periphytic diatom community. Of the 89 taxa classified, eleven taxa were recorded as abundant from at least one station. *Nitzschia dissipata* was the most numerically abundant diatom in the study.

Diversity and similarity indices were incorporated in the evaluation of the data. Tymochtee Creek stations had a greater diversity than Sandusky River stations. Similarity index values generally showed a lack of pattern in diatom community structure in the Sandusky-Tymochtee system.

A COMPARISON OF THE WINTER DIATOM FLORA OF THE SANDUKSY RIVER AND TYMOCHTEE CREEK

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INTRODUCTION

The epilithic diatom floras of the Sandusky River and a major tributary, Tymochtee Creek, were analyzed for species composition, relative abundance, diversity, and community similarities.

Tymochtee Creek is a major tributary to the Sandusky River (fig. 1). The confluence of Tymochtee Creek and the Sandusky River is located in Wyandot County near Tymochtee, Ohio, and is approximately 110 km. from the mouth of the Sandusky River. Both aquatic systems drain primarily agricultural land and flow over dolomitic bedrock.

The Sandusky River flows for 209.5 km through four northern Ohio counties: Crawford, Wyandot, Seneca and Sandusky. It has an average gradient of 0.75 m/km (Ohio Dept. Nat. Res., 1960) and an average flow of 1021 cfs (FWPCA, 1968). The Sandusky River drains an area of over 4,000 km^2. The river is a source of water and receives sewage-treatment-plant effluent for 66,000 people in four major towns as well as from small and medium sized industrial facilities (SIRCH, 1972).

Tymochtee flows from its source in Marion County to its confluence in Wyandot County for a total length of 88.3 km, draining an area of approximately 775 km^2 (Ohio Dept. Nat. Res., 1960). There are no major industrial facilities or cities located within the Tymochtee Creek drainage area.

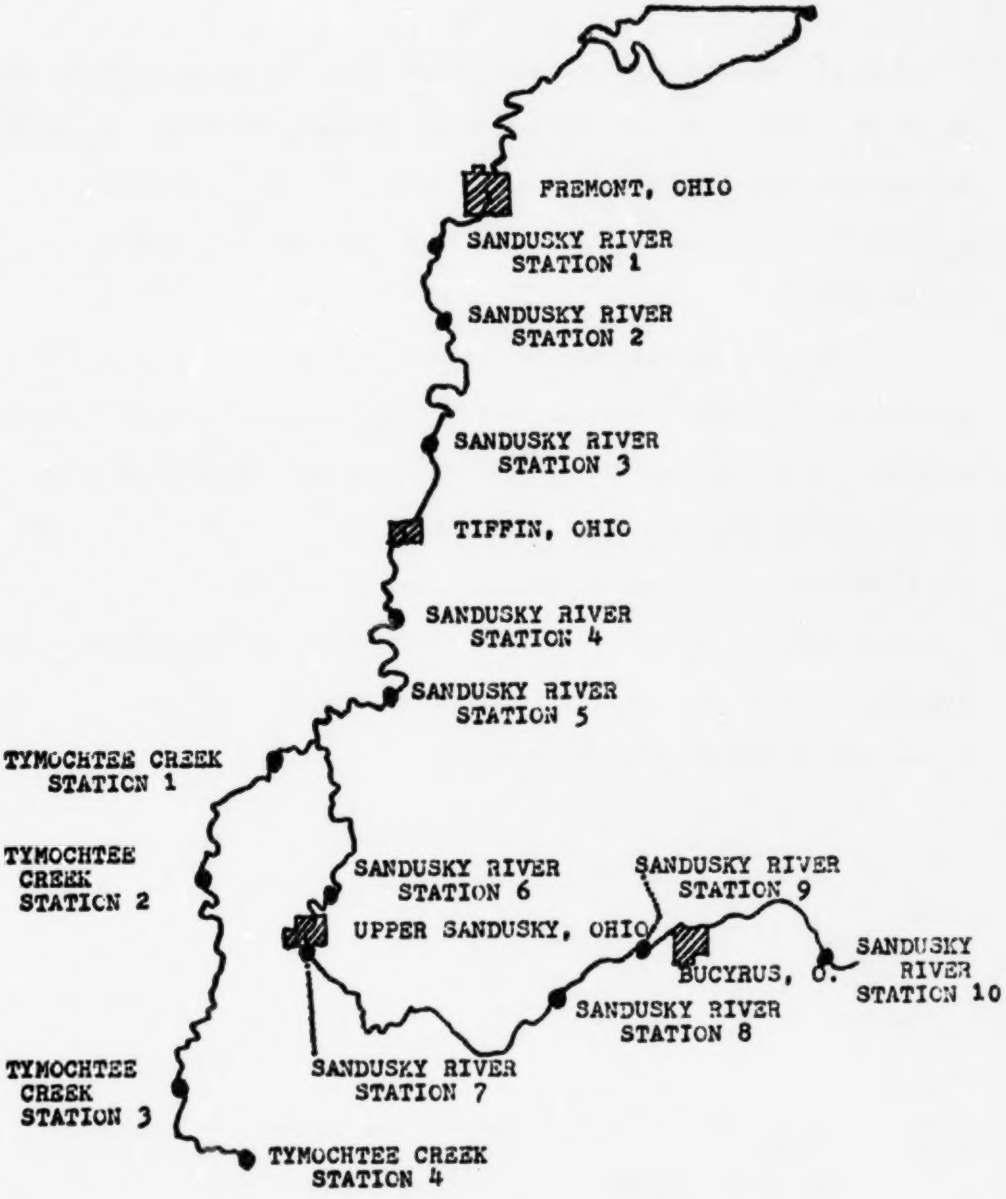
FREMONT, OHIO
SANDUSKY RIVER STATION 1
SANDUSKY RIVER STATION 2
SANDUSKY RIVER STATION 3
TIFFIN, OHIO
SANDUSKY RIVER STATION 4
SANDUSKY RIVER STATION 5
TYMOCHTEE CREEK STATION 1
TYMOCHTEE CREEK STATION 2
SANDUSKY RIVER STATION 6
UPPER SANDUSKY, OHIO
SANDUSKY RIVER STATION 9
BUCYRUS, O.
SANDUSKY RIVER STATION 10
SANDUSKY RIVER STATION 8
SANDUSKY RIVER STATION 7
TYMOCHTEE CREEK STATION 3
TYMOCHTEE CREEK STATION 4

Figure 1 - Sampling stations and major cities of the Sandusky River and Tymochtee Creek.

MATERIALS AND METHODS

The 14 sampling stations are indicated in Figure 1. The ten stations on the Sandusky River were collected on February 15, 1975. The four stations on Tymochtee Creek were collected on March 6, 1975. All samples were randomly selected from rock substrates. The rocks were gently removed from the water and scraped.

The organic material was oxidized by the cold hydrogen peroxide-potassium dichromate technique (van der Werff, 1955) to enable classification of the diatoms. Subsamples of the cleaned material were mounted on glass slides with Hyrax mounting medium. The initial field on each slide was randomly selected and the slide was scanned to obtain a 500 valve count.

Four species diversity indices were calculated for each station, and Simpson's similarity index (SI) was calculated for each possible combination of any two of the 14 sampling stations.

$$SI = \frac{\sum_{j=1}^{S} P_{1j}P_{2j}}{\sqrt{\left(\sum_{j=1}^{S} P_{1j}^{2}\right)\left(\sum_{j=1}^{S} P_{2j}^{2}\right)}}$$

$$P_{ij} = \frac{\text{the no. of indiv. for the } j^{\underline{th}} \text{ taxa in the } i^{\underline{th}} \text{ community}}{\text{the no. of indiv. in the } i^{\underline{th}} \text{ community}}$$

S = the no. of taxa in the two communities combined

RESULTS

A total of 89 diatom taxa representing 21 genera were observed (table 1).

Table 1: Survey of relative abundance of diatoms at each sampling station*

Diatoms observed	Relative abundance at each station													
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
Achnanthes hauckiana Grun.					R	R			R			A	R	U
A. *lanceolata* var. *dubia* Grun.		R								R	R			U
A. *lanceolata* var. *lanceolata* (Bréb.) Grun.						U		R	R	R		R		
Amphora bullatoides Hohn & Hellerm.												U	R	R
A. *ovalis* var. *pediculus* Kütz			U		R	U			C		U	C	R	C
Caloneis bacillaris (Greg.) Cl.		R	R			R					U	C	C	R
Cocconeis pediculus Ehr.	R	R												

Table 1: Continued

Diatoms observed	Relative abundance at each station													
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
C. placentula var.														
lineata (Ehr.) V. H.		U			R					R	U	U		U
Cyclotella														
meneghiniana Kütz.					R		R				R		R	
Cymatopleura solea														
(Bréb.) W. Sm.														R
Cymbella prostrata														
(Berk.) Cl.														R
C. sinuata Greg.											R			U
C. ventricosa Kütz.											R	R		
Diploneis puella														
(Schum.) Cl.														R
Fragilaria vaucheriae														
(Kütz.) Peters.								R	R					
Frustulia rhomboides														
(Ehr.) DeT.		R												R

Table 1: Continued

Diatoms observed	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
	Relative abundance at each station													
Gomphonema angustatum var. *angustatum* (Kütz.) Rabh.														R
G. angustatum var. *producta* Grun.												R		
G. bohemicum Reichelt & Fricke				R										
G. lingulatum var. *constricta* Hust.												C		
G. olivaceum (Lyng.) Kütz.	R	C	R	A	R	R	C	R		U	R	R		
G. pachycladum Bréb. (sensu: V.H., pl. 25, f. 31)												R		
G. parvulum var. *micropus* (Kütz.) Cl.														R
G. parvulum var. *parvulum* Kütz.				R							R	R		U

Table 1: Continued

Diatoms observed	Relative abundance at each station													
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
G. parvulum var. *subelliptica* Cl.			R											
Gomphonema unknown #1		R		R				R	R		U			R
Gyrosigma acuminatum (Kütz.) Rabh.											R		R	R
G. nodiferum (Grun.) Reim. comb. nov.			R										U	R
Melosira angustissima var. *granulata* O. F. Müll.		R												
M. varians Ag.												R		
Meridion circulare var. *circulare* (Grev.) Ag.													R	
M. circulare var. *constrictum* (Ralfs.) V.H.										R				

Table 1: Continued

Diatoms observed	Relative abundance at each station													
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
Navicula biconica **Patr.**							R							
N. cincta **var.** ***rostrata*** **Reim.**			R					R	U		R	R		U
N. confervacea **var.** ***peregrina*** **(W. Sm.) Grun.**							R							
N. cryptocephala **var.** ***cryptocephala*** **Kütz.**								R						R
N. cryptocephala **var.** ***veneta*** **(Kütz.) Rabh.**	U	U	U	U		R	U				U		R	R
N. graciloides **A. Mayer**					R		R							
N. heufleri **var.** ***heufleri*** **Grun.**		R			R									
N. heufleri **var.** ***leptocephala*** **(Bréb. ex. Grun.) Patr. comb. nov.**												R		

Table 1: Continued

Diatoms observed	Relative abundance at each station													
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
N. lanceolata (Ag.) Kütz.		R										R		
N. luzonensis Hust.		U	R			R		U	U		R			
N. menisculus var. *menisculus* Schum.						R								R
N. menisculus var. *upsaliensis* (Grun.) Grun.	U	U	U	U	R	R	U	U	R		U	U		R
N. minima Grun.		U	U						U		R			U
N. mutica var. *tropica* Hust.												R		
N. radiosa var. *tenella* (Bréb. ex. Kütz.) Grun.		C	A	U	U	C	U	C	C	R	C	R	A	
N. salinarum var. *intermedia* (Grun.) Cl.	R	U	R	U	U			R	R		U	R	R	R

Table 1: Continued

Diatoms observed	Relative abundance at each station S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
N. salinarum var.														
salinarum Grun.								R						
N. secreta var.														
apiculata Patr.		U	U	U	C	C	A	A	C	R	C	C	C	U
N. seminuloides Hust.	R	U	R	U			R				R			
N. seminulum Grun.		R	R						C	R	R			
N. symmetrica Patr.		R												R
N. tantula Hust.		U	C			R		R	A					C
N. tenelloides Hust.														R
N. tenera Hust.											R			
N. tripunctata														
(O.F. Müll.) Bory	R	U	C	U	C	A	R	U	C		R	U	A	R
N. viridula (Kütz.)														
Kütz. emend, V.H.				R	U	U	C	A	U	A				
Navicula unknown #1													R	
Navicula unknown #2				R										

Table 1: Continued

Diatoms observed	Relative abundance at each station													
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
Navicula unknown #3					R									
Nitzschia amphibia Grun.			U		R	R			U		R	R		U
N. angustata var. *acuta* Grun.											R	R	R	
N. apiculata (Greg.) Grun.	R		R		R		R		U		R	R	R	R
N. capitellata Hust.													R	
N. dissipata (Kütz.) Grun.	A	A	C	A	A	C	A	C	C	R	A	C	A	A
N. fonticola Grun.		R					R							
N. frustulum var. *frustulum* Kütz.											R			R
N. frustulum var. *perpusilla* (Rabh.) Grun.		U	U		A	R		R	R		U			U
N. holsatica Hust.					R									

Table 1: Continued

Diatoms observed	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
	Relative abundance at each station													
N. hungarica Grun.							R					R		
N. linearis W. Sm.		R												
N. palea (Kütz.) W. Sm.		R					R							
N. sigma (Kütz.) W. Sm.					R							U		
N. sigmoidea (Ehr.) W. Sm.												R		
N. tropica Hust.		U	R		U					U		R		U
N. tryblionella var. *victoriae* Grun.		R									R	U	R	R
N. vermicularis (Kütz.) Grun.													R	
Nitzschia unknown #1							R						U	R
Rhoicosphenia curvata (Kütz.) Grun. ex. Rabh.		R	R	U	U	C			R	C	A	C	U	C
Stauroneis smithii Grun.													R	

Table 1: Continued

Diatoms observed	Relative abundance at each station													
	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
Stephanodiscus astrae var. *minutula* (Kütz.) Grun.			R											
S. invisitatus Hohn & Hellerm.		R	R											
Surirella angustata Kütz.								R	R					
S. brightwelli W. Sm.												R		
S. iowensis Lowe											U	C	R	U
S. ovata var. *ovata* Kütz.	U	U	R	U	R	U	A	U		R	C	C	C	U
S. ovata var. *pinnata* (W. Sm.) Hust.	R				R		R							
Synedra rumpens Kütz.														U

*R=rare, less than 1% of the community; U=uncommon, 1% to 5% of the community; C=common, 5% to 20% of the community; and A=abundant, over 20% of the diatom community.

Of the 89 taxa observed, 40 were found in both the Sandusky River and Tymochtee Creek; 21 only in the Sandusky River; and 28 taxa exclusively in Tymochtee Creek.

The following 11 taxa represented 20% or more of the diatom community at one or more stations: *Achnanthes haukiana* Grun., *Gomphonema olivaceum* (Lyng.) Kütz., *Navicula radiosa* var. *tenella* (Breb. ex. Kütz.) Grun., *Navicula secreta* var. *apiculata* Patr., *Navicula tantula* Hust., *Navicula tripunctata* (O. F. Müll.) Bory, *Navicula viridula* (Kütz.) emend. V.H., *Nitzschia dissipata* (Kütz.) Grun., *Nitzschia frustulum* var. *perpusilla* (Rabh.) Grun., *Rhoicosphenia curvata* (Kütz.) Grun. ex Rabh., and *Surirella ovata* var. *ovata* Kütz. *Navicula viridula* accounted for 82% of the flora at station 10 of the Sandusky River. *Nitzschia dissipata* comprised 93% of the community at station 1 of the Sandusky River, and was overall the most abundant diatom observed in the Sandusky River and Tymochtee Creek.

Tymochtee Creek generally had a greater species diversity at each of its sampling sites than did the Sandusky River (table 2). The species diversity index values were lowest at stations 1 of the Sandusky River and highest at stations 2 and 4 of Tymochtee Creek.

The greatest Simpson's similarity was between stations 1 and 2 of the Sandusky River with an index value of 0.96680. The greatest dissimilarity was between stations 1 and 10 of the Sandusky River with a value of 0.00503 (table 3).

Histograms were prepared to evaluate the Simpson's similarity data in groupings. Similarity index values comparing adjacent sampling stations were organized on a histogram with the index values of nonadjacent sampling stations (fig. 2). No apparent difference was observed. A histogram considering

Table 2

Species diversity index values of each diatom community

Sampling station	Species diversity*	Simpson's index**	Information theory DBAR †	MacArthur's index ††
S-1	0.0220	0.1345	0.5658	1.1551
S-2	0.0640	0.7429	3.1657	3.8665
S-3	0.0520	0.7967	3.0214	4.8807
S-4	0.0320	0.7022	2.3708	3.3424
S-5	0.0480	0.7087	2.4770	3.4160
S-6	0.0380	0.8381	2.9699	6.1140
S-7	0.0400	0.7900	2.6883	4.7254
S-8	0.0380	0.7926	2.6722	4.7847
S-9	0.0440	0.8390	3.2500	6.1471
S-10	0.0260	0.3134	1.0840	1.4551
T-1	0.0680	0.8391	3.4223	6.1507
T-2	0.0700	0.9017	3.8643	9.9913
T-3	0.0500	0.8253	3.0279	5.6720
T-4	0.0820	0.8801	3.9607	8.2221

* S/N; S = no. species, N = no. indiv.

** (1-sum $(N_1(N_1-1)))/N(N-1))$; N_1 = no indiv. in each species, N = total no. indiv. (Simpson, 1949).

† - sum (N_1/N) $(\log_2(N_1/N))$; N_1 = no. indiv. in each species, N = total no indiv. (Shannon, 1948).

†† 1/sum$(N_1/N)^2$; N_1 = no. indiv. in each species, N = total no. indiv. (MacArthur, 1972).

Table 3: Simpson's similarity index values for comparisons of communities

Sta.	Sampling Stations												
	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	T-1	T-2	T-3	T-4
S-1	.9688	.2982	.7832	.8472	.2916	.5846	.0473	.1863	.0050	.7534	.3460	.5627	.8563
S-2		.4264	.8707	.8700	.3838	.6229	.0518	.2838	.0109	.7673	.3625	.6479	.8662
S-3			.2886	.3707	.5938	.2607	.0475	.5661	.0168	.3842	.1702	.7766	.3748
S-4				.6788	.3100	.5914	.0442	.1731	.0366	.6438	.3010	.4894	.6897
S-5					.3902	.5336	.0519	.2448	.0783	.6936	.3303	.5953	.8129
S-6						.4086	.0511	.4734	.0962	.6433	.3684	.8091	.4591
S-7							.0738	.2405	.1316	.6877	.4214	.5272	.6138
S-8								.0322	.0806	.0549	.0288	.0592	.0476
S-9									.0665	.2302	.1966	.4286	.3751
S-10										.0782	.0279	.0180	.0462
T-1											.4767	.6138	.8755
T-2												.3564	.5100
T-3													.5271

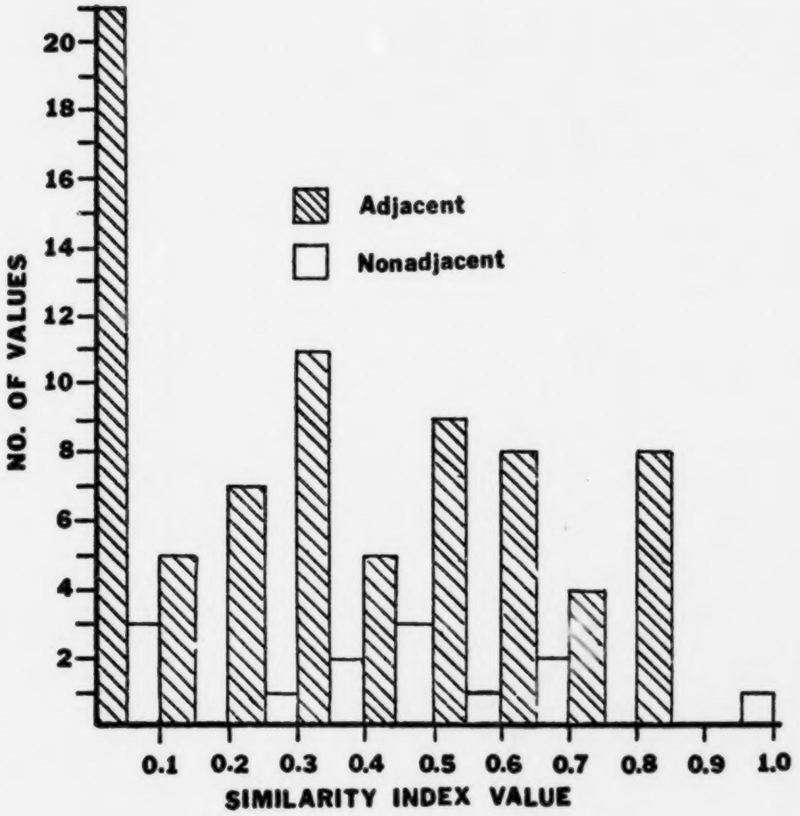

Figure 2 - Histogram showing the Simpson's similarity index values between adjacent stations and between nonadjacent sampling stations.

similarity index values that compared Tymochtee Creek stations with other Tymochtee Creek stations, Sandusky River sampling stations with other Sandusky River stations, the Tymochtee Creek stations with Sandusky River sampling stations (fig. 3) showed no distinct distributional differences. A histogram demonstrating the distribution of the Simpson's similarity index values that compared the Tymochtee Creek sampling stations and Sandusky River sampling stations downstream from the Tymochtee Creek confluence, stations 1 to 5, the Tymochtee Creek sampling stations and Sandusky River stations 6 to 10, upstream from the confluence, and the Sandusky River stations above and below the confluence, showed a higher similarity value distribution when the Tymochtee Creek stations and Sandusky River stations below the confluence were compared (fig. 4).

DISCUSSION AND CONCLUSION

Between the sampling dates of February 15 for the Sandusky River stations and March 6 for the Tymochtee Creek stations, high water conditions caused a scouring of the epilithic diatom communities. Patrick (1967) indicates that as diatom species colonized glass slides, the number of species initially increases greatly and later decreases at a rate dependent upon the growth rate of the diatoms. The scouring and subsequent partial recolonization by diatoms are believed to reflect this initial colonization period when larger numbers of diatom taxa are present and to be the primary reason for the higher species diversity in the Tymochtee Creek samples than in the Sandusky River samples.

Simpson's similarity index was used to detect similarities in the diatom community structures. The index values were grouped to reveal any general community structure patterns.

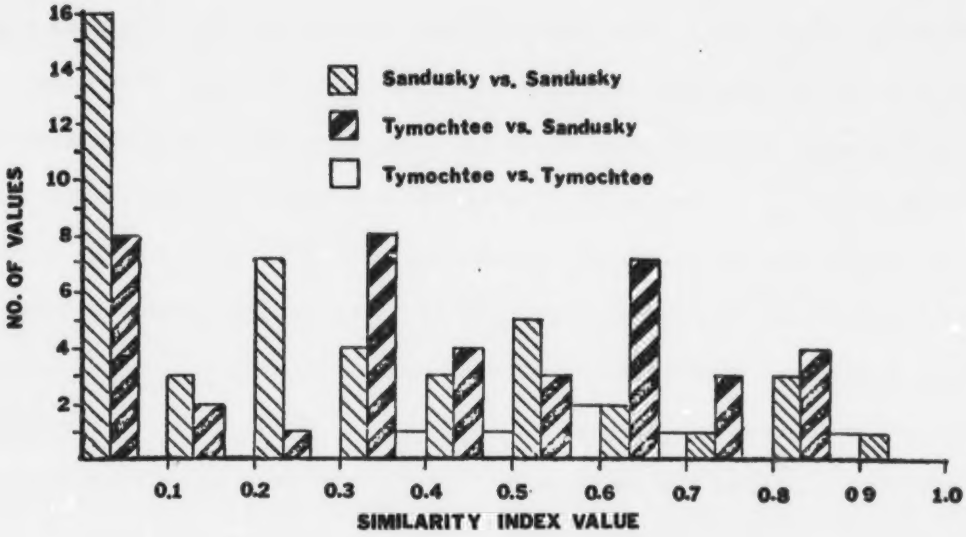

Figure 3 - Histogram showing the Simpson's similarity index values between Sandusky River sampling stations, between Tymochtee Creek stations, and between Sandusky River stations and Tymochtee Creek stations.

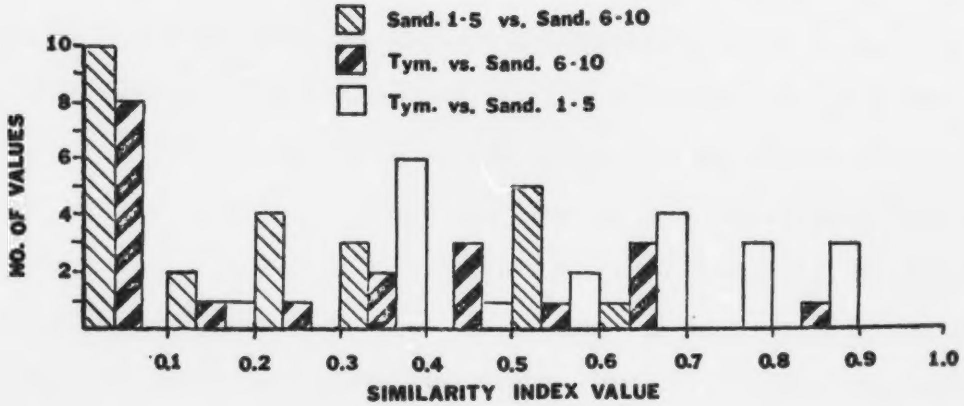

Figure 4 - Histogram showing the Simpson's similarity index values between Sandusky River stations 1-5 and Sandusky River stations 6-10, between Tymochtee Creek stations and Sandusky River stations 6-10, and between Tymochtee Creek sampling stations and Sandusky River stations 1-5.

No relationship in general community structure was observed between adjacent sampling stations as opposed to similarities between sampling stations separated by one or more sampling sites; i.e. stations 1 and 2, 2 and 3, 3 and 4, and so forth were no more similar than stations 1 and 3, 2 and 4, 3 and 5, 3 and 9, and so forth.

No distinctly greater similarities were observed in the diatom community structures within the Sandusky River sampling stations and within the Tymochtee Creek as opposed to similarities comparing Sandusky River stations to Tymochtee Creek stations. A basic diatom flora appears to be universally found throughout the sampled system.

No basic diatom flora pattern for effects of upstream community diatom flora upon downstream diatom community structure was observed. A greater similarity between Sandusky River stations downstream from the Tymochtee confluence and Tymochtee Creek stations was detected compared to similarities between Sandusky River stations downstream and stations upstream from the confluence and between Sandusky River stations upstream from the confluence and Tymochtee Creek stations. Since the similarity index values computed for comparing Sandusky River stations downstream and stations upstream from the confluence were not higher as the index values for comparisons between Sandusky River stations downstream from the confluence and Tymochtee Creek station were, it cannot be assumed that there is any great effect of upstream diatom community flora upon downstream community structure. A greater similarity between environments of stations downstream from the confluence on the Sandusky River and stations of Tymochtee Creek is assumed to be the reason for the higher distribution of the Simpson's similarity index values for the corresponding stations' comparisons.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Mary Petrowski for her aid in programming Simpson's similarity index. Recognition is also given to Dr. Rex Lowe for his teachings and technical advice.

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ABSTRACT

THE FISHES OF THE SANDUSKY RIVER SYSTEM, OHIO

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A general description of the Sandusky River system is given before the events of dams, drainage ditches, increased turbidity and other pollutants, silt depostion on the substrate, decrease or elimination of aquatic vegetation, and organic enrichment of the waters by domestic, industrial, and agricultural sources. The former abundance of fishes is discussed.

Subsequent modifications of the stream system is briefly outlined. Changes during the past and present abundance of the recorded 88 fish species and possible reasons for these changes are given.

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THE FISHES OF THE SANDUSKY RIVER SYSTEM, OHIO

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The Sandusky River system, located in north-central Ohio, drains portions of all or parts of eight counties and has a drainage area of 1,420 square miles. The topography varies from quite level to slightly rolling, except in the headwaters of a few tributaries where gradients are higher. Consequently, stream gradients are low to moderate.

Before 1850, erosion had been reduced to a minimum because the soils, with very few exceptions, were tied down by forests and prairies. Swamp forests, some of which were contiguous with the Black Swamp, covered a considerable portion of the land. The remaining portion of the drainage area contained islands of oak-hickory and prairie. Apparently the waters were rarely turbid. Marshes and lowlands, containing an abundance of land and aquatic vegetation, were extensively flooded during spring, the water slowly retreating as the summer advanced. This vegetation, in decomposing, precipitated solids which assisted in clarifying the water, although staining it. The decomposing vegetation furnished both food and cover for the young of several fish species. Because of the apparent great clarity of the water, the fish fauna was composed of many species intolerant to turbity and silted substrates, some extremely so.

In the buildings of the Winous Point Shooting Club, Ottawa County, there are four wall maps of surveys of the Club grounds and upper Sandusky Bay. These were completed in June of 1820, July of 1864, November of 1873 and October of 1894. The latter, surveyed by Edgar H. Brennan, a civil engineer, is the most detailed and elaborate and agrees with the others in general. This 1894 survey outlines several sections of stone fences and walls which, since at least 1930, have been under water. Presumably they were built during former periods of low lake levels. The surveys also indicate that the Sandusky River flowed between well-defined marshy banks, which extended eastward from its present mouth to Eagle Island. This portion is now the upper Sandusky and Muddy bays. Muddy Creek had an equally well-defined channel and entered directly into the Sandusky River, not Muddy Bay as it does today.

Before 1900 several species of fishes were recorded from this section which have not been recorded farther upstream. The majority of these required an abundance of submerged aquatics or a non-silted substrate composed of clear sands, gravels or soft muck. I, therefore, include this section as formerly being the lowest part of the Sandusky River.

The early Ohio literature contains many references to the vast abundance of fishes in Lake Erie and its tributaries, and to their huge spring and fall migrations. Brown (1815) wrote that in the nearby Maumee River "the quantity (of fishes) was almost incredible" and that in the Maumee River during "Some days there were not less than 1000 taken with the hook." Brown also states that the Sandusky River was no exception; it "abounds with several kinds of valuable fish."

The Lake Erie tributaries, with their important spawning and nursery areas, formerly contributed greatly to the huge populations of some species of fishes in the lake (Trautman, 1957). As was also recorded for the Maumee River (Trautman, 1957) many fish species migrated into and spawned in the Sandusky River before the event of dams, extensive drainage, increased turbidity and other pollutants.

Apparently the two "falls" in the Sandusky River in the vicinity of the present Ballville normally were not barriers to upstream fish migration. One was only eight feet high and a portion of it was "not perpendicular", where with much difficulty "wooden canoes" could be pulled over it. The other was a rapids rather than a falls (Howe, 1900:588).

Formerly, spawning conditions in the lowland swamp forest and flooded prairies were favorable for sturgeons and muskellunges. From recent investigations of the upper reaches of Muskellunge Creek, a tributary of the Sandusky River in Sandusky County, it is apparent that it should have contained a most favorable spawning habitat. Both sturgeon and muskellunge are nearing extirpation in Lake Erie waters today.

The following published accounts are used as illustrations of the abundance of fishes in former times. Col. James Smith (Howe, 1900:589 90) was a captive of the Indians between the years 1755 and 1759. One spring he and others traveled down the Sandusky River until they "came to a little lake (Sandusky Bay) at the mouth of the Sandusky" stopping at a Wyandot town called Sunyendeand. There they caught "rock-fish" in a small tributary, which were migrating "up the creek to spawn," the first night catching "scarcely enough for present use." Mr. Thompson, a prisoner from Virginia, told Smith that he could "catch more fish than the whole town could make use of." He felled a tree so that it dropped across the creek, placing stakes along its prostrate trunk "to prevent fish from passing up, leaving only a gap at one side." He sat beside this gap at night with "a hoop net of elm bark" frequently "hauling out two or three rock-fish that would weigh about five or six pounds each." After capturing "about a wagon load" of fishes, he closed the gap before daylight, thereby preventing fishes from migrating. The next morning when the Indians saw the large heap of fish which Thompson had caught and the large number "confined in the water" they spent the "chief part of that day in killing rock-fish." Having no salt to preserve them, they left many of the fishes lying on the bank. "After some time great numbers of turkey buzzards and eagles collected together and devoured them." The literature records various other types of brush dams that were used by the white man. One on the Great Miami River, Butler County, Ohio made possible the taking of "5,000 weight," on 3-4 September, during the downstream migration of 1793 or 1794 (Wilson, 1935:53-54). Keeler (1904) wrote:

> What the people along the river most wanted in those early days was salt, more especially as the river teemed with fish. 'Every spring,' says Dr. Brainard's manuscript (1816), 'the pickerel and white bass were found in such multitudes all along the rapids, that it was often quite impossible to ride a horse across the ford till much exertion was made to drive them away and make room for his feet. Fish had in the meantime become a good article for traffic with southern teamsters, who occasionally came in with six horse wagons loaded with flour to exchange. Hence in addition to the much-needed flour, at times a good deal of cash was paid for our choice fish, and our town became noted not only for its romantic situation, its productive soil, and the history of its inhabitants, but for its extensive fisheries.'
> The Fremont Freeman of May 24, 1851, has this item: 'This has been one of the most prolific seasons for fishing for years. On one ground there were about 100,000 white bass caught in one week, about three hundred barrels. There have not been far from a thousand barrels caught within the past two weeks.'
> I. M. Keeler, who came to Lower Sandusky (Fremont) in 1840, says that it was difficult to cross the river in a boat, in the spring

> season when the fish were going up. They filled the whole channel of water. He frequently saw three or four wagon loads of white bass taken out with one draw of the seine. The barrels of packed fish branded Dickinson, Birchard and Grant were to be found all through the east. Sturgeon weighing from seventy to a hundred pounds were common; cat fish and muscalonge from twenty to fifty pounds. The fishermen would haul a sturgeon up on the banks and cut his throat like sticking a pig. The carcasses would lie there till dry and then be piled up and set afire. They burned like a pitch-pine log.

Dr. Cole (1820:134-38), in a discussion of the lower Sandusky River and village of Lower Sandusky, or Fort Stephenson, now Fremont, states, "Every spring a great many fish are taken in the river; they are the pike, pickerel, cat-fish, and white bass. The inhabitants eat fresh and salted fish the year round."

FISH SPECIES RECORDED FOR THE SANDUSKY RIVER

Since 1850 more than 90 localities in the Sandusky River, and more than 50 in the Upper Sandusky Bay west of Eagle Island, have been investigated, some localities more than 30 times. The majority of the records before 1925 were taken from the literature; the remainder were verbally given to me by older residents concerning their observations primarily between 1850 and 1900. Since 1925 observations and collections have been made by others or myself, and those before 1957 having been published (Trautman, 1957).

To date, 88 species of fishes[1] have been reliably recorded, all except a few having been preserved in the fish collections of The Ohio State University

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[1] For locality records of these species see Trautman, 1957.

Museum of Zoology. Of these, 41 species show little or no evidence of a decrease, and except for a few, all are tolerant to silt turbidity and other pollutants. Thirty-five species have definitely decreased in abundance and of these nine have not been recorded since 1940. All require waters of little turbidity and/or an abundance of submerged aquatic vegetation. The species in this group also show marked decreases in abundance or have been extirpated in other stream systems in Ohio. Of the remaining 12 species, six appear to be recent invaders, such as the Sea Lamprey *(Petromyzon marinus)* which has invaded from the east, and the Suckermouth Minnow *(Phenocobius mirabilus)* and Orangespotted Sunfish *(Lepomis humilis)* from the west (Trautman, 1957). The latter two are very tolerant to turbility and a silty substrate. The remainder have been introduced by man. Those most tolerant to turbidity and a silted substrate, such as the Carp *(Cyrpinus carpio)* and Goldfish *(Carassius auratus)* are very numerous in the river today. Those intolerant to turbidity, if present at all, occur very sparingly.

There undoubtedly have been present since 1850, other fish species in the Sandusky River which have not been recorded. This river system was less thoroughly investigated before 1900 than was the similar Maumee River system. Partly because of the more thorough investigations of the Maumee, 102 fish species have been recorded for that system, 14 more than for the Sandusky. It is highly significant that all of the 14 species require waters of outstanding clarity and that three of these have not been recorded since 1893 and one, the Harelip Sucker *(Lagochila lacera)* is apparently extince throughout its range.

Lower Sandusky Bay and adjacent Lake Erie have six species not recorded for the Sandusky River which probably occurred in this stream at some time, at least as strays.

In summary: More than half of the 88 fish species recorded for the Sandusky River have decreased in numerical abundance since 1850 or have been extirpated. These include those species prevented from migrating upstream to spawn because of dams; those whose spawning habitat has been largely destroyed by agricultural practices, ditching and draining; those which require considerable aquatic vegetation; and/or those intolerant to turbidity. Many species of former economic importance, such as Sturgeon, Muskellunge and Walleye, have been largely or entirely eliminated.

ACKNOWLEDGMENTS

I wish to thank Dr. Robert Meeks for allowing me to examine the survey maps belonging to The Winous Point Shooting Club, and to those innumerable individuals who have aided me in my investigations of the Sandusky River during the past 50 years.

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ABSTRACT

THE ORIGIN AND DISTRIBUTION OF THE NAIAD MOLLUSKS OF THE SANDUSKY RIVER BASIN

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During 1970 and 1971, the Sandusky River and its major tributaries were collected, yielding 26 species of naiades. However, the distribution of these species within the Sandusky River basin was variable.

This variable distribution within the Sandusky may be due to a number of factors. Most naiades were collected from barren bedrock where they would be more susceptible to current and predators. Higher gradients appear to limit the distribution of some naiades within the Sandusky; perhaps because of a limitation of the fish host or the juvenile naiad. Impoundments seem to be the main man-made factor restricting the distribution of naiades within the river, although domestic pollution may be important downstream from Bucyrus.

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ABSTRACT

STREAM SIDES AND RESERVOIRS AS MIGRATORY BIRD REFUGES

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The wooded edges and hillsides of the Sandusky Basin streams, the large reservoirs, and the numerous farm ponds are especially important to migratory birds because: 1. They are situated where there is a convergence of migration routes. 2. They provide habitat in an area where there has been and continues to be development of intensive agricultural and urban sprawl. 3. Their cool weather production of flying insects provides food at critical times for insectivorous birds while their production of aquatic animal life provides food for water birds at every season.

Examples of the distribution of emergence of aquatic insects are stoneflies in March, alderflies in April, caddisflies in May, caddisflies in September, and mayflies, waterboatmen, and caddisflies in October. Various craneflies and midges also emerge in spring and fall.

Random censuses of migrants along the edge of the Sandusky River in the Tiffin area suggest a heavy use. On May 13, 1973 along a quarter mile stretch there were orioles, thrushes, swallows, vireos, and eight species of warblers. On May 23 there were 11 species of warblers, tanagers, Empidonax flycatchers, redbreasted nuthatches, Swainson thrushes, twenty Philadelphia vireos, and ten redeyed vireos. Thirty-four species were counted in 1½ hours on May 2, 1974.

The large reservoirs were used by many water birds as soon as they contained any water. They have been primarily responsible for 10% increase in number of species of birds recorded for Seneca County in the last ten years. Also waterbirds which were of casual or rare occurrence are now relatively common. Of twenty-one new records for the county, fourteen were of water-related birds and seven of these can be directly attributed to Beaver Creek Reservoir. In March 22 there were about 5000 birds of 11 different species, two of which were different from March 21. It is theorized that the inland reservoirs are becoming part of the Lake Erie ecosystem and that more new species will visit them in the future.

SANDUSKY RIVER BORDERS AND RESERVOIRS AS MIGRATORY BIRD REFUGES

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The Sandusky Basin wooded valleys, the large reservoirs and numerous farm ponds are especially important to migratory birds because they are situated where there is a concentration of migration routes; they provide habitat in an area where there has been great development of intensive agriculture and urban sprawl; their cool weather production of aquatic flying insects provides food at critical times.

MIGRATION ROUTES

The migratory behavior of North American birds must be very plastic since tremendous changes must have developed with the cycles of glaciation. We may speculate that there are inherited tendencies to direct migrations along the ancient river systems which flowed toward and away from the area in consideration. In any case, the present day Atlantic and Mississippi flyways for waterfowl fan out westward and eastward to converge around the western end of Lake Erie. Also there is some latitudinal migration from the northern plains across the Great Lakes to the Atlantic and return. The shallow west end of Lake Erie and the adjacent marshes no doubt have been optimal feeding grounds for waterfowl in the recent past. Since much of Lake Erie habitat has been lost or been made unsuitable for migrants, the ponds and reservoirs in the Sandusky Basin are becoming important stops for these waterfowl.

SMALL LANDBIRD MIGRANTS

The small nocturnal migrants probably move in a broad front across eastern United States. The north-south pass formed by the Scioto-Sandusky river systems would tend to concentrate them along this route. This is more likely in northern Ohio since the Sandusky River leads toward the Catawba peninsula, the Lake Erie Islands, and the Pelee Peninsula--stepping stones across the lake. The land route to Canada around the west end of Lake Erie is also nearby.

The wooded edges of the Sandusky are becoming yearly more important to many passerines and others because forested land has been reduced to less than 10% of the total vegetational cover in the valley. This remaining 10% is being reduced at a rate of about 1% per year. Whereas the soybean and cornfields are excellent feeding areas for many waterfowl and certain shorebirds, they provide no foraging for insectivorous woodland birds.

The third feature of the basin streams important to migrants is, in fact, the cool weather production of flying insects. The high fertility of the Sandusky streams combined with their relatively steep gradient results in bumper crops of aquatic insects each year. The peak of emergence occurs throughout May and June and consists primarily of caddisflies.

Some typical insect emergence events were recorded in 1973. On March 2 there were emergences of large stoneflies which were fed upon by Cedar Waxwings. On April 23 there was a notable emergence of alderflies. Caddisfly emergence was significant by May 1. On September 11 and 12 there were large caddisfly flights and as usual these and mayflies continued emerging during October in lower numbers. Corixids made dispersal flights in October. Throughout the season there was a continual emergence of various aquatic *Diptera*. Undoubtedly migrating warblers, vireos, and flycatchers fed upon all these insects.

RECORDS OF SMALL MIGRANTS

Bird populations and migrations have been observed regularly in Seneca County for the past 25 years. Much of the data collected by a number of individuals has been summarized by Knoblaugh (1968). Observers have the impression that there is a concentration of small migrants along the river in both the spring and the fall.

Some examples of concentrations are: on May 13, 1973, in a quarter mile stretch from Muss St. to Bacon's dam in Tiffin there were eight species of warblers plus orioles, northern thrushes, swallows, red-breasted nuthatches, sapsuckers and tanagers--these were migrants in addition to what we assumed were resident birds.

On May 23rd the same stretch of narrow habitat along the river produced 11 species of warblers including about 30 bay-breasted individuals; also there were 20 Philadelphia vireos and 10 red-eyed vireos, six tanagers, Empidonax flaycatchers, red-breasted nuthatches, and northern thrushes. The Philadelphia vireos are significant since they have never been seen in such large numbers except along the western edge of Lake Erie.

On May 2, 1974 the river edge and the air space over the river were censused for 1½hours in a quarter mile stretch. There were 34 species, most of which were nonresident. On May 9, 1974 after three cold days, nine groups of swifts and one group of barn swallows were feeding along two miles of the river north of Tiffin. This total of 300 or so birds supports the idea of the river producing food on critical cold days.

Thomas and Paula Bartlett discovered a Kirtland's warbler along Rock Creek in the Heidelberg area April 30, 1975. Hintz found a Yellow-throated warbler by the Sandusky River in May 1975. Of the seven records of sightings of Kirtlands in the Toledo area between 1907 and 1968, four have been on the Catawba peninsula and Bass Islands (Campbell). So this particular sighting strongly supports the theory of the importance of the Sandusky River migratory route.

DAY MIGRANTS

It is known that day migrants, although advancing on a wide front, are much influenced by major topographic features. Such features often strongly "funnel" diurnal migrants; i.e. the migration route becomes locally very narrow. This strengthens the popular notion that bird migrants travel along narrow avenues (VanTyne and Berger, 1959).

In 1950 Lincoln published his famous "Four Flyways Theory". Although much of this has now been modified, the basic notion that there are major routes traveled by a majority of day migrants is supported by the location of the major topographic features--the Atlantic Coast, the Mississippi River, the Rocky Mountains, and the Pacific Coast and Mountains.

The Atlantic and Mississippi Flyways each have what one could call tributaries which meet in the western end of Lake Erie. The Atlantic has two tributaries: (1) one comes up the Potomac River, across western Pennsylvania to Lake Erie and then west along the lake; (2) the other comes up through the Carolinas, Kentucky, and up through the middle of the state of Ohio to the lake. The Mississippi also has two tributaries: (1) one comes up the Ohio River and through the middle of Ohio to the lake; (2) the other comes up the Wabash River,across Indiana and along the Maumee River to the lake. The Sandusky River Basin is related primarily to the two tributaries that come through the middle of the state. The Sandusky would seem to be the major topographical feature in northern Ohio which guides these tributaries.

If this is true,then along this line there should be fairly high concentrations of *Gaviidae, Anatidae, Charadriidae,* and *Scolopacidae* which are birds that may migrate by day or night (Brewster, 1886). The reservoirs around Columbus have consistantly had good populations of these orders and so has Lake Erie. Therefore, we feel that there are movements between the lake and the Columbus area reservoirs during migration. However, before 1972 there was no great evidence of this movement in Seneca County. Since then new facts have come to light which support this idea.

In 1968 Hintz and Knoblaugh prepared a paper on the best birdwatching areas of Seneca County and a list of all the species of birds which had been seen in the county with estimates of their abundance. The records show that 205 species had been recorded for Seneca County by 1968 and that 50 of these species were water related.

A new list of bird sightings for Seneca County was prepared by Bartlett in January 1975 and this was further updated in the spring of 1975. The new total is 228 species, an increase of 23 species in seven years. This 10% increase is significant for an area that keeps fairly complete records.

Two factors are responsible for this increase. First, there has been an increase of observer time in the field. The second factor, which we feel is the major one, is the presence of Beaver Creek Reservoir which has built in 1972. Of the 23 new species, 14 are water birds and seven can be directly attributed to the new reservoir.

Not only has the reservoir helped to add new species, but it has changed the status of several other species. Two examples are the common loon and the horned grebe The common loon was considered rare with fewer than six recorded sightings before 1968. Since 1972 there have been numerous sightings during migration and several winter and summer records. The horned grebe was also considered rare with fewer than six records before 1968. This year the horned grebe was present at the reservoir from March 19 to May 7, 1975. On several days more than 20 individuals were present. Further examples of the importance of Beaver Creek Reservoir are these sample counts. Note the rapid turnover on the two consecutive days.

March 21, 1975

200+	Lesser Scaup	12+	Horned Grebe
200+	Redheads	6+	Mallards
100+	Red-breasted Merganser	6+	Black Duck
50	Whistling Swans	2	Pied-billed Grebe
30+	American Widgeon	2	American Coot
30+	Ring-necked Ducks	1	Gadwall

March 22, 1975

2500+	Lesser Scaup	10+	Mallards
1500+	Ring-necked Ducks	6+	Horned Grebe
500+	Redheads	6+	Pied-billed Grebe
200+	American Widgeon	4+	Red-breasted Mergansers
150+	American Coots	3	Blue-winged Teal
50+	Buffleheads		

Numbers such as these were unheard of in the county before the construction of the reservoir with respect to the above mix of species. Great concentrations of Black Ducks and Mallards have occurred on the Sandusky River in the late fall and winter--as many as 100,000 birds, on that portion in Seneca County.

Rare and endangered birds which have recently been seen about Beaver Creek Reservoir and along the Sandusky River are the greater scaup, merlin, immature and adult bald eagles, and ospreys.

SUMMARY

Good records of bird populations and migrations in Seneca County have been kept for the past 25 years. In recent years, 23 new species have been added and 14 of these are water birds. Beaver Creek Reservoir is responsible for many of these additions and for the great increase of a number of species which were formerly more or less accidental in the county. Small land bird migrants tend to move along the Sandusky River edges where there is a continuous gallery of suitable habitat and abundant food. The Sciota-Sandusky-Bass Island migration route is probably a natural postglacial flyway which has now become more critical for survival of migrants in a heavily farmed and urbanized region.

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ABSTRACT

A SEASON COMPARISON OF BENTHIC MACROINVERTEBRATES BROKEN SWORD AND TYMOCHTEE CREEKS

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Benthic macroinvertebrates were collected from natural substrates of Broken Sword and Tymochtee Creeks on October 19, 1974. The sampling device used was the BOP (Barton, Olive, Prater). Representative organisms found were Diptera, Ephemeroptera, Plecoptera, Gastopoda, Pelecypoda, Trichoptera, Odonata, and Plesiopora. Relative abundance and density were calculated for each taxon.

Broken Sword and Tymochtee Creeks are tributaries of the Sandusky River and are located in agricultural areas. The most striking differences between the streams are flow and substrate. Tymochtee Creek has well developed riffle areas; Broken Sword does not and is characterized by a more silty, muddy substrate. Five stations have been established on Broken Sword Creek, and eight stations have been established on Tymochtee Creek.

Community structure of the two streams was similar with respect to organisms found; however, differences in dominant genera, based on relative abundance were observed. The dominant genera of Broken Sword Creek were *Stictochironomus* (Diptera), *Caenis* (Ephemeroptera), *Limnodrilus* (Plesiopora), and *Chironomus* (Diptera). Relative abundance values in percent were 21.57, 20.85, 19.07, and 12.83 respectively. The dominant genera of Tymochtee Creek were *Stictochironomus, Cheumatopsyche* (Trichoptera), tribe Pentaneurini (Diptera), and *Limnodrilus*. Relative abundance values in percent were 20.00, 10.37, 7.37, and 6.82 respectively.

Chemical parameters of the two streams have been taken, although no attempt to correlate water chemistry with organisms has been made at this time. This aspect will be completed at a later date.

These data are a portion of a complete benthic macroinvertebrate study (September 1974-September 1975) by Bankieris and Barker. The study is supported in part by an institutional grant from the National Science Foundation.

ABSTRACT

THE AQUATIC COLEOPTERA OF THE SANDUSKY RIVER, OHIO

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Aquatic coleoptera were collected monthly from 10 sampling stations in the Sandusky River. The sampling period was from October 26, 1973 through September 21, 1974. Samples were obtained during the second or third week of each month, with the exception of December (missed because of exceedingly high water). The stations were numbered in kilometers from the mouth of the river. Following picking and sorting, the specimen were classified and enumerated. Coleoptera classifed were *Dubiraphia quadrinota, D. vitta, D. spp., Machronychus glabratus, Stenelmis crenata, S. sexlineata, S. spp., S. vittipennis, Ectopria nervosa, Peltodyted duodecimpunctatus, Berosus spp., Hydrocchus spp., Paracymus spp., Lutrochus laticeps, Psephenus herricki, Ataenius spp.*, and two unknown species. Nine families were collected with three being terrestial families that were probably washed into the river.

Relative abundance and standing crop per M^2 were calculated. Larva forms of *Dubiraphia* and *Stenelmis* could not be classified to species. *Stenelmis* had the greatest relative abundance with 31.6 percent while *Psephenus herricki* had the second greatest with 22.1 percent.

The mean number of coleoptera per M^2 per month at all stations were calculated with August, 1974 having the largest standing crop ($421/M^2$) and May, 1974 having the least ($30/M^2$). The mean number of coleoptera per M^2 station was calculated with a high of $425/M^2$ at station 34.7 and a low of $0/M^2$ at station 187.3. The greatest number of different species was collected at station 81.7 with 9 and the least number of different species was collected at station 187.3 with 0 species.

No correlations to chemical parameters has been attempted at this time, however this aspect will be completed in the very near future.

The study was supported in part by a grant from The Ohio Biological Survey, while with the Department of Biological Sciences at B.G.S.U.

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AQUATIC COLEOPTERA OF THE SANDUSKY RIVER (OHIO)

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INTRODUCTION

The aquatic coleoptera discussed here represent only one group of taxa taken from a very extensive study of all the benthic macroinvertebrates of the Sandusky River (Ohio). Further, the results were not obtained from methods specifically designed for the purpose of sampling aquatic coleoptera. Thus, some species that one would expect to occur, are absent from the results, i.e., *Optioservus trivittatus, Microcylloepus, Helichus basalis, H. fastigiatus,* and *H. lithophilus*. These species have been collected in streams in Southern Ohio but may not be present in the Sandusky River.

No correlations to chemical parameters have been attempted at this time; however, this aspect will be completed soon and current plans are to publish the entire macroinvertebrate study in an Ohio Biological Survey publication. The entire study was supported in part by a grant from The Ohio Biological Survey.

METHODS

Ten sampling stations were selected on the Sandusky River and numbered in kilometers from the mouth of the river (figure 1 and table 1). The stations were selected to represent the habitat for that particular segment of river. Samples were collected monthly from each of the sampling stations. Riffle, pool, and marginal samples were combined at each station in order not to bias the results. Sampling sites at each station were selected by the stratified random sampling technique. The sampling apparatus used was

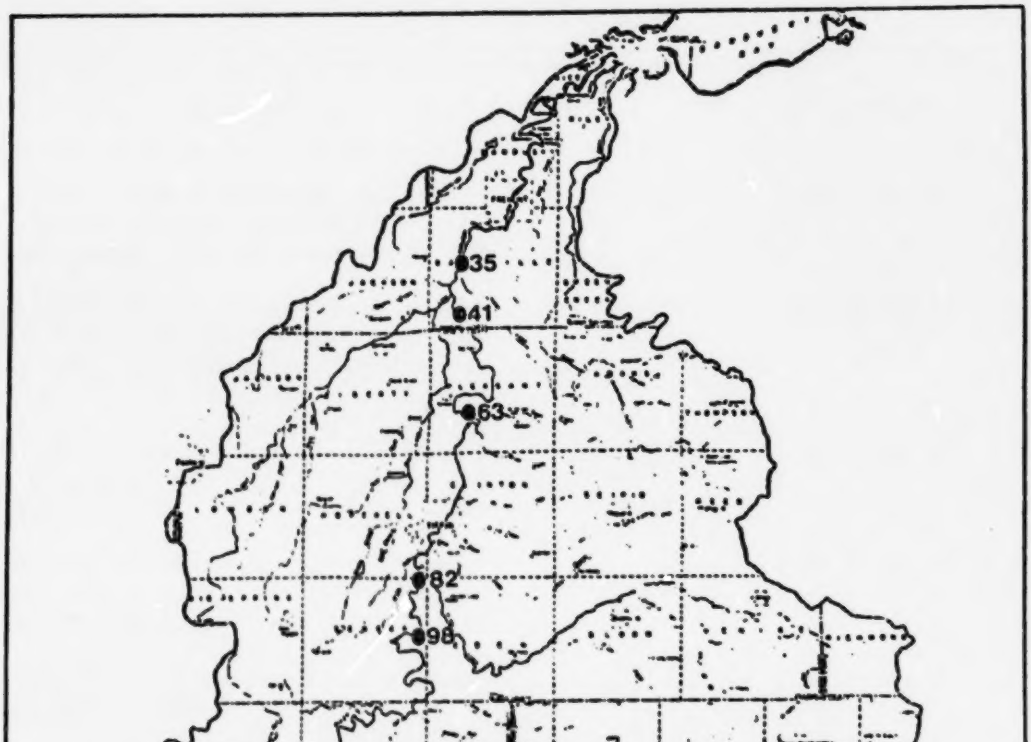
35
41
63
82
98
134
143
187
175
207
SANDUSKY RIVER BASIN

Figure 1. Location of sampling stations

Table 1: Sandusky River station locations for benthic macroinvertebrate study, October 26, 1973 - September 21, 1974.

Station No.	Location
2 (34.7 km.)	Seneca Co. Sandusky River. 2 mi. E. St.Rt. 53, on Rice Road, Tindall Bridge, Fremont West Quadrangle R. 15E, T.4N, Sec. 17
3 (41.3 km.)	Seneca Co. Sandusky River. 3 mi. E. St. Rt. 53, on Darr Road, Gilmore Bridge, Fremont West Quadrangle R. 15E, T.4N, Sec. 32.
4 (62.7 km.)	Seneca Co. Sandusky River. 1 mi. E. St. Rt. 53, on Co. Rd. 38. Tiffin North Quadrangle. R. 15E, T.3N, Sec. 32.
5 (81.7 km.)	Seneca Co. Sandusky River. 2 mi E. St. Rt. 53, on Co. Rd. 90. Tiffin Quadrangle R. 14E, T1N, Sec. 13 (Gauging Station)
6 (98.0 km.)	Wyandot Co. Sandusky River. 1 mi. W. of Mexico on Mexico Rd. Sycamore Quadrangle R. 14E, T1S, Sec. 1.
7 (134.3 km.)	Wyandot Co. Sandusky River. 1 mi. N. St. Rt. 23 on Co. Rd. 121. Upper Sandusky Quadrangle. R. 14E, T2N, Sec. 21 (Gauging Station)
8 (143.3 km.)	Wyandot Co. Sandusky River. ½ mi. E. St. Rt. 199 on Co. Rd. 62. Upper Sandusky Quadrangle. R. 14E, T3S, Sec. 5.
9 (174.7 km.)	Crawford Co. Sandusky River. 1 mi. W. of Wyandot Rd. on Caldwell Rd. Oceola Quadrangle. R. 15E, T3S, Sec. 17.
10 (187.3 km.)	Crawford Co. Sandusky River. 6 mi. W. Bucyrus on Kestetter Rd. Oceola Quadrangle. R. 16 , T3S, Sec. 10. (Gauging Station).
11 (207.3 km.)	Crawford Co. Sandusky River. ½ mi. W. Leesville Rd. on Lower Leesville Rd. North Robinson Quadrangle. R. 21W, T20N. Sec. 12.

the BOP (Barton, Olive, Prater) and the techniques were those used by Olive (1973). The sampling period was from October 26, 1973 through September 21, 1974. Samples were obtained during the second or third week of each month, with the exception of December, which was missed because of exceedingly high water. Water samples were taken and analyzed by the staff of the River Laboratory at Heidelberg College, Tiffin, Ohio. The stations were picked and sorted and the speciments were classified and enumerated.

RESULTS

Nine families and 18 species of coleoptera were collected during the sampling period (table 2). Relative abundance and standing crop per m^2 were calculated. The larva forms of *Dubiraphia* and *Stenelmis* could not be classified to the species level. *Stenelmis* had the greatest relative abundance with 31.6 percent while *Psephenus herricki* was second with 22.1 percent.

The mean number of coleoptera per m^2 per month at all stations was calculated; August, 1974 had the largest standing crop ($421/m^2$) (figure 2). The mean number of coleoptera per m^2 per station was calculated with a high of $425/m^2$ at station 34.7 and a low of $0/m^2$ at station 187.3 (figure 3). The greatest number of different species, nine, was collected at station 81, and the least number of different species, zero, was collected at station 187.3 (figure 4).

Tables were prepared for each of the 10 sampling stations illustrating the families and species collected, dates of collection, the mean for each species for the 11 month of collection, and the mean for each species for the number of months a particular species was collected at that particular station.

Table 2: Relative abundance of coleoptera taxa collected from the Sandusky River October 26, 1973 - September 21, 1974

Taxa	Relative Abundance (percent)
Anobiidae	
unknown spp.	0.5
Dytisidae	
unknown spp.	0.5
Elmidae	
Dubiraphia quadrinotata Say	0.5
D. vittata Say	3.4
D. spp.	19.0
Machronychus glabratus Say	3.4
Stenelmis crenata Say	1.5
S. sexlineata Sand.	11.0
S. vittipennis Zimm.	1.0
S. spp.	31.6
Eubriidae	
Ectopria nervosa Melsh.	2.0
Haliplidae	
Peltodyted duodecimpunctatus Say	0.5
Hydrophilidae	
Berosus spp.	0.5
Hydrochus spp.	0.5
Paracymus spp.	0.5
Limnichidae	
Lutrochus laticeps Casey	1.0
Psephenidae	
Psephenus herricki DeKay	22.1
Scarabaeidae	
Ataenius spp.	0.5

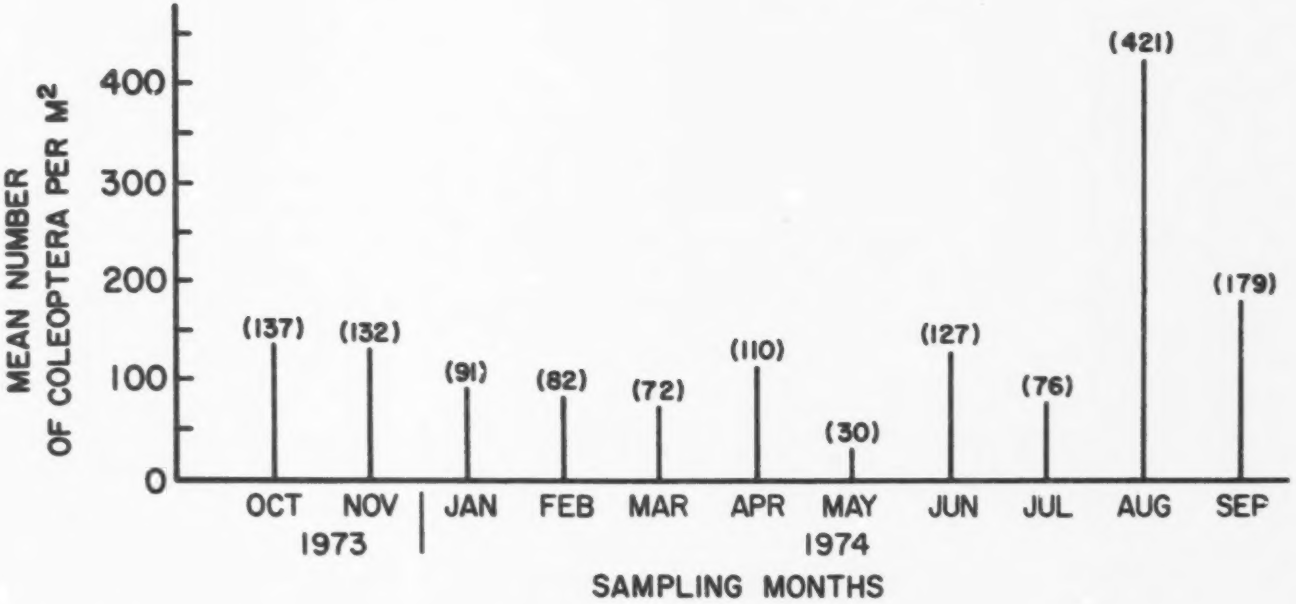

Figure 2. MEAN NUMBER OF COLEOPTERA PER SQUARE METER PER MONTH AT ALL STATIONS
OCT. 26, 1973 — SEPT. 21, 1974

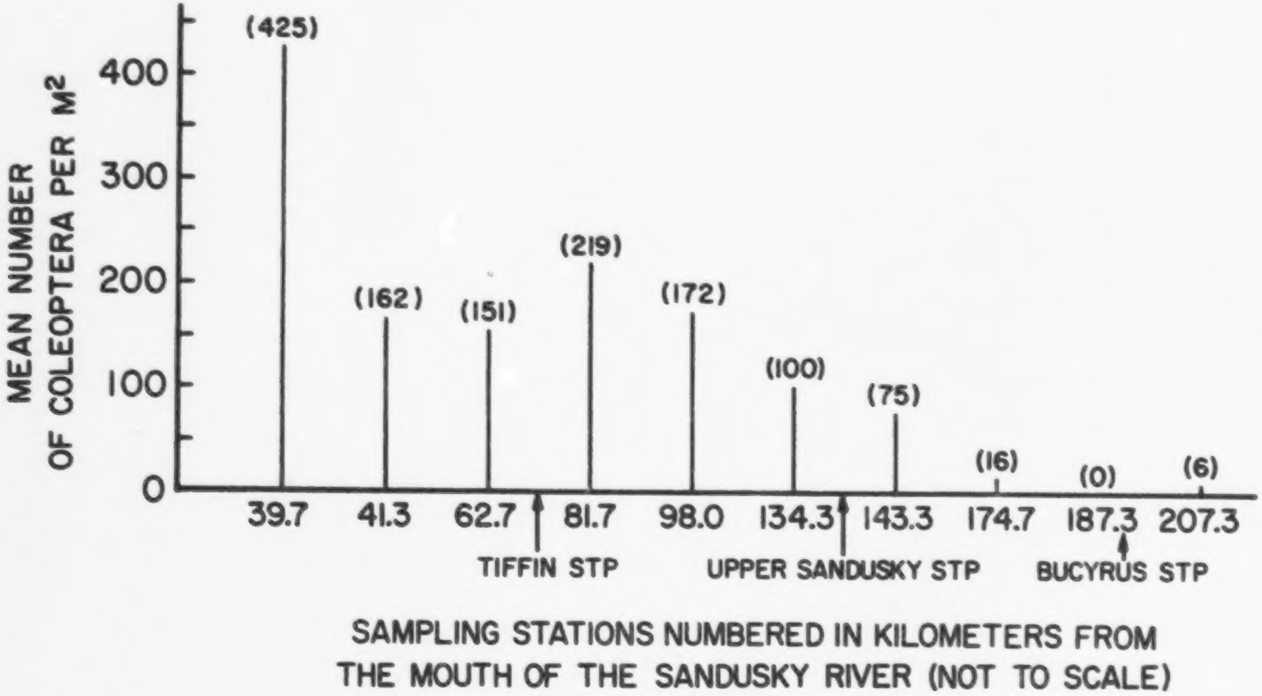

Figure 3. MEAN NUMBER OF COLEOPTERA PER SQUARE METER PER STATION OCT. 26, 1973 — SEPT. 21, 1974

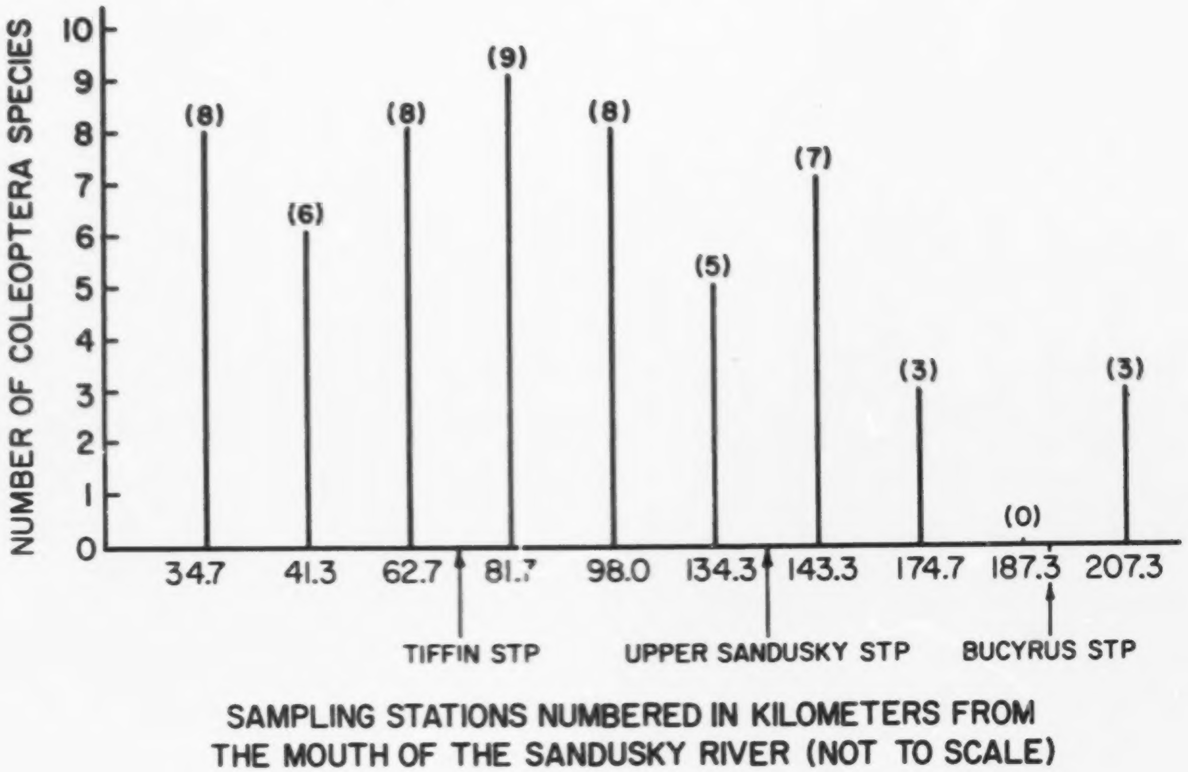

Figure 4. TOTAL NUMBER OF COLEOPTERA SPECIES PER STATION
OCT. 26, 1973 — SEPT. 21, 1974

The specimens collected each date are recorded as larve (L) or adult (A). Also, the total individuals and total species were recorded for each sampling date per sampling station (tables 3-12).

DISCUSSION

The families Haliplidae and Hydrophilidae are not considered to be of great significance in water quality studies because they are entirely too mobile as adults (Hart, 1974). Few species of these two families were collected and most of those were classified only to the genus level. The Anobiidae, Dytisidae, and Scarobaeidae are not benthic, and two are not true aquatic coleoptera, thus the collection of these during the sampling period probably was somewhat accidental.

The greatest number of species collected was in the family Elmidae Very little is known about the life cycles of the Elmidae as well as the Psephenidae (the second most abundant family) (Hart, 1974). The elmids seem to have at least five instars, and they pupate under stones or in wood in water; the pupal stage lasts about two weeks. They over-winter in all stages (figure 3-12).

Brown (1974) mentions that the adults of the Psephenidae are much less known than the larvae, widely known as water pennies. This is certainly true in the Sandusky River study, because only 10 adults were collected at station 81.7 on August 16, 1974. However, adult males are riparian, often occurring in abundance upon stones or other objects protruding from the water in riffles or rapids of shallow streams (Murvosh, 1971). The sampling procedure would generally preclude collecting the adults. *Lutrochus laticeps* of the family Limnichidae have a similar microhabitat of that of *Psephenus* (Brown, 1970).

Table 3: Coleoptera* taxa collected at Station 2 (34.7 km) Sandusky River (Ohio) October 26, 1973 - September 21, 1974

	SAMPLING DATES													
FAMILY/SPECIES	Oct 26 1973	Nov 16 1973	Jan 14 1974	Feb 16 1974	Mar 21 1974	Apr 20 1974	May 24 1974	Jun 14 1974	Jul 20 1974	Aug 16 1974	Sep 21 1974	Total per yr	Mean for 11 mos.	Mean for # mos. Sampled
Anobiidae														
unknown sp.														
Dytisidae														
unknown sp.														
Limnichidae														
Lutrochus latriceps														
Elmidae														
Machronychus glabratus														
Dubiraphia quadrinotata														
Dubiraphia vittata								31(A)		10(A)		41	3.7	20.5
Dubiraphia spp.	31(L)	177(L)						16(L)	10(L)	21(L)		255	23.1	51.0
Stenelmis crenata										10(A)	16(L)	26	2.3	13.0
Stenelmis sexlineata								734(A)	10(A)	229(A)	438(A)	1411	128.2	352.7
Stenelmis vittipennis											16(A)	16	1.4	16.0
Stenelmis spp.	10(L)			78(L)		125(L)		16(L)	31(L)	2250(L)	297(L)	2807	255.1	401.0
Eubriidae														
Ectopria nervosa														
Haliplidae														
Peltodyted duodecimpunctatus														
Hydrophilidae														
Berosus sp.										10(A)		10	0.9	10.0
Hydrochus sp.														
Paracymus sp.														
Psephenidae														
Psephenus herricki		10(L)			10(L)			16(L)		31(L)	47(L)	114	10.3	22.8
Psephenus sp.														
Scarabaeidae														
Ataenius sp.														
Total Number	41	187	---	78	10	125	---	813	51	.2561	814	4680	425.4	
Total Species	2	2	---	1	1	1	---	5	3	7	5	8		

*per meter^2

Table 4: Coleoptera* taxa collected at Station 3 (41.3 km) Sandusky River (Ohio) October 26, 1973 - September 21, 1974

FAMILY/SPECIES	SAMPLING DATES Oct 26 1973	Nov 16 1973	Jan 14 1974	Feb 16 1974	Mar 21 1974	Apr 20 1974	May 24 1974	Jun 14 1974	Jul 20 1974	Aug 16 1974	Sep 21 1974	Total per yr	Mean for 11 mos.	Mean for # mos. Sampled
Anobiidae														
unknown sp.														
Dytisidae														
unknown sp.														
Limnichidae														
Lutrochus latriceps														
Elmidae														
Machronychus glabratus		10(L)										10	0.9	10.0
Dubiraphia quadrinotata														
Dubiraphia vittata														
Dubiraphia spp.	42(L)	42(L)	31(L)	21(L)	21(L)				21(L)	42(L)	141(L)	361	32.8	45.1
Stenelmis crenata														
Stenelmis sexlineata			10(A)	10(A)						10(A)	31(A)	61	5.5	8.0
Stenelmis vittipennis														
Stenelmis spp.	42(L)	21(L)	21(L)	188(L)	31(L)	10(L)			68(L)	448(L)	47(L)	871	79.1	96.7
Eubriidae														
Ectopria nervosa			10(L)	10(L)								20	1.8	10.0
Haliplidae														
Peltodyted duodecimpunctatus														
Hydrophilidae														
Berosus sp.														
Hydrochus sp.														
Paracymus sp.														
Psephenidae														
Psephenus herricki	10(L)		135(L)	42(L)		219(L)	21(L)	10(L)	21(L)			458	41.6	65.4
Psephenus sp.														
Scarabaeidae														
Ataenius sp.														
Total Number	94	73	207	271	52	229	21	10	105	500	219	1781	161.9	
Total Suecies	3	3	5	5	2	2	1	1	3	3	3	6		

*per meter^2

Table 5: Coleoptera* taxa collected at Station 4(62.7 km) Sandusky River (Ohio) October 26, 1973 - September 21, 1974

	SAMPLING DATES													
FAMILY/SPECIES	Oct 26 1973	Nov 16 1973	Jan 14 1974	Feb 16 1974	Mar 21 1974	Apr 20 1974	May 24 1974	Jun 14 1974	Jul 20 1974	Aug 16 1974	Sep 21 1974	Total per yr	Mean for 11 mos.	Mean for # mos. Sampled
Anobiidae														
unknown sp.														
Dytisidae														
unknown sp.														
Limnichidae														
Lutrochus latriceps								10(L)			16(L)	26	2.3	13.0
Elmidae														
Machronychus glabratus						16(L)				10(A)		26	2.3	13.0
Dubiraphia quadrinotata														
Dubiraphia vittata					16(A)					10(A)		26	2.3	13.0
Dubiraphia spp.		52(L)	16(L)									68	6.1	34.0
Stenelmis crenata														
Stenelmis sexlineata	115(A)		31(A)			16(A)	16(A)	42(A)		322(A)	31(A)	574	52.1	82.0
Stenelmis vittipennis														
Stenelmis spp.	208(L)	302(L)	16(L)		94(L)	94(L)	16(L)	10(L)		21(L)	94(L)	855	77.7	95.0
Eubriidae														
Ectopria nervosa					47(L)					10(L)		57	5.1	28.5
Haliplidae														
Peltodyted duodecimpunctatus														
Hydrophilidae														
Berosus sp.														
Hydrochus sp.														
Paracymus sp.														
Psepnenidae														
Psephenus herricki	10(L)				16(L)							26	2.3	13.0
Psephenus sp.														
Scarabaeidae														
Ataenius sp.														
Total Number	333	354	63	—	157	142	32	62	—	374	141	1658	150.7	
Total Species	2	2	3	—	3	4	2	3	—	4	3	8		

*per meter^2

Table 6: Coleoptera* taxa collected at Station 5 (81.7 km) Sandusky River (Ohio) October 26, 1973 - September 21, 1974

FAMILY/SPECIES	SAMPLING DATES													
	Oct 26 1973	Nov 16 1973	Jan 14 1974	Feb 16 1974	Mar 21 1974	Apr 20 1974	May 24 1974	Jun 14 1974	Jul 20 1974	Aug 16 1974	Sep 21 1974	Total per yr	Mean for 11 mos.	Mean for # mos. Sampled
Anobiidae														
unknown sp.														
Dytisidae														
unknown sp.														
Limnichidae														
Lutrochus latriceps														
Elmidae														
Machronychus glabratus										31(L)	10(L)	41	3.7	20.5
Dubiraphia quadrinotata														
Dubiraphia vittata										31(A)		31	2.8	31.0
Dubiraphia spp.	42(L)		21(L)	47(L)	16(L)							126	11.4	31.5
Stenelmis crenata			10(A)									10	0.9	10.0
Stenelmis sexlineata			10(A)					10(A)		10(A)		30	2.7	10.0
Stenelmis vittipennis										10(A)		10	0.9	10.0
Stenelmis spp.	281(L)	125(L)	167(L)	156(L)	328(L)	52(L)	115(L)	52(L)	292(L)	146(L)	250(L)	1964	178.5	178.5
Eubriidae														
Ectopria nervosa														
Haliplidae														
Peltodyted duodecimpunctatus														
Hydrophilidae														
Berosus sp.														
Hydrochus sp.														
Paracymus sp.														
Psephenidae														
Psephenus herricki										10(A)		10	0.9	10.0
Psephenus sp.			52(L)		31(L)		10(L)			63(L)	31(L)	137	17.0	37.4
Scarabaeidae														
Ataenius sp.														
Total Number	323	125	260	203	375	52	125	62	292	301	291	2409	219	
Total Species	2	1	5	2	3	1	2	2	1	7	3	9		

*per meter^2

Table 7: Coleoptera*taxa collected at Station 6 (98.0 km) Sandusky River (Ohio) October 26, 1973 - September 21, 1974

FAMILY/SPECIES	SAMPLING DATES Oct 26 1973	Nov 16 1973	Jan 14 1974	Feb 16 1974	Mar 21 1974	Apr 20 1974	May 24 1974	Jun 14 1974	Jul 20 1974	Aug 16 1974	Sep 21 1974	Total per yr.	Mean for 11 mos.	Mean for # mos. Sampled
Anobiidae														
unknown sp.		16 (A)										16	1.4	16.0
Dytisidae														
unknown sp.														
Limnichidae														
Lutrochus latriceps														
Elmidae														
Machronychus glabratus			31 (L)									31	2.8	31.0
Dubiraphia quadrinotata			16 (A)									16	1.4	16.0
Dubiraphia vittata						16 (A)						16	1.4	16.0
Dubiraphia spp.	203 (L)	203 (L)		16 (L)		16 (L)	10 (L)			109 (L)	63 (L)	620	56.3	88.5
Stenelmis crenata														
Stenelmis sexlineata			31 (A)			94 (A)		10 (A)				135	12.2	45.0
Stenelmis vittipennis														
Stenelmis spp.	78 (L)	63 (L)	16 (L)	47 (L)		281 (L)		167 (L)		203 (L)	47 (L)	902	82.0	112.7
Eubriidae														
Ectopria nervosa														
Haliplidae														
Peltodytes duodecimpunctatus														
Hydrophilidae														
Berosus sp.														
Hydrochus sp.														
Paracymus sp.														
Psephenidae														
Psephenus herricki			16 (L)			47 (L)	10 (L)	31 (L)			47 (L)	151	13.7	30.2
Psephenus sp.														
Scarabaeidae														
Ataenius sp.														
Total Number	281	282	110	63	---	454	20	208	---	312	157	1887	171.5	
Total Species	2	3	5	2	---	5	2	3	---	2	3	8		

*per meter^2

Table 8: Coleoptera* taxa collected at Station 7 (134.3 km) Sandusky River (Ohio) October 26, 1973 - September 21, 1974

FAMILY/SPECIES	SAMPLING DATES Oct 26 1973	Nov 16 1973	Jan 14 1974	Feb 16 1974	Mar 21 1974	Apr 20 1974	May 24 1974	Jun 14 1974	Jul 20 1974	Aug 16 1974	Sep 21 1974	Total per yr.	Mean for 11 mos.	Mean for # mos. Sampled
Anobiidae														
unknown sp.														
Dytisidae														
unknown sp.														
Limnichidae														
Lutrochus latriceps														
Elmidae														
Machronychus glabratus	16(L)													
Dubiraphia quadrinotata												16	1.4	16.0
Dubiraphia vittata														
Dubiraphia spp.														
Stenelmis crenata					16(L)		10(L)	10(L)	16(L)	115(L)	83(L)	250	22.7	41.6
Stenelmis sexlineata			16(A)											
Stenelmis vittipennis												16	1.4	16.0
Stenelmis spp.	16(L)	104(L)	109(L)			31(L)		31(L)	78(L)		31(L)	400	36.3	57.1
Eubriidae														
Ectopria nervosa														
Haliplidae														
Peltodyted duodecimpunctatus														
Hydrophilidae														
Berosus sp.														
Hydrochus sp.														
Paracymus sp.														
Psephenidae														
Psephenus herricki	16(L)	63(L)	63(L)	78(L)		42(L)	10(L)	10(L)	125(L)	10(L)		417	37.9	46.3
Psephenus sp.														
Scarabaeidae														
Ataenius sp.														
Total Number	48	167	188	78	16	73	20	51	219	125	114	1099	99.9	
Total Species	3	2	3	1	1	2	2	3	3	2	2	5		

*per meter^2

Table 9: Coleoptera* taxa collected at Station 8 (143.3 km) Sandusky River (Ohio) October 26, 1973 - September 21, 1974

	SAMPLING DATES												
FAMILY/SPECIES	Oct 26 1973	Nov 16 1973	Jan 14 1974	Feb 16 1974	Mar 21 1974	Apr 20 1974	May 24 1974	Jun 14 1974	Jul 20 1974	Aug 16 1974	Sep 21 1974	Total per yr	Mean for 11 mos.	Mean for # mos. Sampled
Anobiidae														
unknown sp.														
Dytisidae														
unknown sp.							10(A)					10	0.9	10.0
Limnichidae														
Lutrochus latriceps														
Elmidae														
Machronychus glabratus														
Dubiraphia quadrinotata														
Dubiraphia vittata											10(A)	10	8.9	10.0
Dubiraphia spp.	219(L)	78(L)		94(L)				31(L)	31(L)	16(L)	10(A)	479	43.5	68.4
Stenelmis crenata														
Stenelmis sexlineata														
Stenelmis vittipennis														
Stenelmis spp.		16(L)	16(L)	21(L)	94(L)	10(L)	42(L)	21(L)				220	20.0	31.4
Eubriidae														
Ectopria nervosa														
Haliplidae														
Peltodyted duodecimpunctatus											21(A)	21	1.9	21.0
Hydrophilidae														
Berosus sp.														
Hydrochus sp.														
Paracymus sp.														
Psephenidae														
Psephenus herricki			16(L)		16(L)		10(L)	10(L)		16(L)	10(L)	78	7.0	13.0
Psephenus sp.														
Scarabaeidae														
ataenius sp.							10(A)					10	0.9	10.0
Total Number	219	94	32	115	110	10	72	62	31	32	51	828	75.2	
Total Species	1	2	2	2	2	1	4	3	1	2	4	7		

*per meter^2

Table 10: Coleoptera*taxa collected at Station 9 (174.7 km) Sandusky River (Ohio) October 26, 1973 - September 21, 1974

FAMILY/SPECIES	SAMPLING DATES Oct 26 1973	Nov 16 1973	Jan 14 1974	Feb 16 1974	Mar 21 1974	Apr 20 1974	May 24 1974	Jun 14 1974	Jul 20 1974	Aug 16 1974	Sep 21 1974	Total per yr	Mean for 11 mos.*	Mean for # mos. Sampled
Anobiidae														
unknown sp.														
Dytisidae														
unknown sp.														
Limnichidae														
Lutrochus latriceps														
Elmidae														
Machronychus glabratus														
Dubiraphia quadrinotata														
Dubiraphia vittata														
Dubiraphia spp.														
Stenelmis crenata														
Stenelmis sexlineata			47(A)									47	4.2	47.0
Stenelmis vittipennis														
Stenelmis spp.	10(L)	10(L)			10(L)	10(L)						40	3.6	10.0
Eubriidae														
Ectopria nervosa														
Haliplidae														
Peltodyted duodecimpunctatus														
Hydrophilidae														
Berosus sp.														
Hydrochus sp.														
Paracymus sp.														
Psephenidae														
Psephenus herricki	21(L)	31(L)		16(L)			10(L)	10(L)				88	8.0	17.6
Psephenus sp.														
Scarabaeidae														
Ataenius sp.														
Total Number	31	41	47	16	10	10	10	10	---	---	---	175	15.9	
Total Species	2	2	1	1	1	1	1	1	---	---	---	3		

*per meter^2

Table 11: Coleoptera*taxa collected at Station 10 (187.3 km) Sandusky River (Ohio) October 26, 1973 - September 21, 1974

	SAMPLING DATES													
FAMILY/SPECIES	Oct 26 1973	Nov 16 1973	Jan 14 1974	Feb 16 1974	Mar 21 1974	Apr 20 1974	May 24 1974	Jun 14 1974	Jul 20 1974	Aug 16 1974	Sep 21 1974	Total per yr	Mean for 11 mos.	Mean for # mos. Sampled
Anobiidae														
unknown sp.														
Dytiscidae														
unknown sp.														
Limnichidae														
Lutrochus latriceps														
Elmidae														
Machronychus glabratus														
Dubiraphia quadrinotata														
Dubiraphia vittata														
Dubiraphia spp.														
Stenelmis crenata						NO SPECIES COLLECTED AT ANYTIME DURING THE INVESTIGATION								
Stenelmis sexlineata														
Stenelmis vittipennis														
Stenelmis spp.														
Eubriidae														
Ectopria nervosa														
Haliplidae														
Peltodyted duodecimpunctatus														
Hydrophilidae														
Berosus sp.														
Hydrochus sp.														
Paracymus sp.														
Psephenidae														
Psephenus herricki														
Psephenus sp.														
Scarabaeidae														
Ataenius sp.														
Total Number														
Total Species														

*per meter^2

Table 12: Coleoptera*taxa collected at Station 11 (207.3 km) Sandusky River (Ohio) October 26, 1973 - September 21, 1974

FAMILY/SPECIES	SAMPLING DATES													
	Oct 26 1973	Nov 16 1973	Jan 14 1974	Feb 16 1974	Mar 21 1974	Apr 20 1974	May 24 1974	Jun 14 1974	Jul 20 1974	Aug 16 1974	Sep 21 1974	Total per yr	Mean for 11 mos.	Mean for # mos. Sampled
Anobiidae														
unknown sp.														
Dytisidae														
unknown sp.														
Limnichidae														
Lutrochus latriceps														
Elmidae														
Machronychus glabratus														
Dubiraphia quadrinotata														
Dubiraphia vittata														
Dubiraphia spp.														
Stenelmis crenata														
Stenelmis sexlineata														
Stenelmis vittipennis														
Stenelmis spp.									16(L)			16	1.4	16.0
Eubriidae														
Ectopria nervosa														
Haliplidae														
Peltodyted duodecimpunctatus														
Hydrophilidae														
Berosus sp.														
Hydrochus sp.									16(A)			16	1.4	16.0
Paracymus sp.									31(A)			31	2.8	31.0
Psephenidae														
Psephenus herricki														
Psephenus sp.														
Scarabaeidae														
Ataenius sp.														
Total Number	---	---	---	---	---	---	---	---	63	---	---	63	5.7	
Total Species	---	---	---	---	---	---	---	---	3	---	---	3		

*per meter^2

At a time when aquatic investigators are grasping for organisms to be used as indicators of water quality, perhaps a closer look at the aquatic coleoptera is needed. Leeches, planarians, and such arthropods as amphipods seem tolerant of soapy water; whereas such forms as elmid and dryopoid beetles are virtually eliminated (Brown, 1966). Brown (1966) further suggested that this differential effect is related to the respiratory mechanisms of the animals concerned. Whereas sewage pollution affects the fauna mainly by promoting excessive bacterial growth and consequent oxygen depletion, soap pollution exerts influence through its effects upon air-water interfaces. Thus, those organisms which employ hydrofuge air film are drastically affected; whereas those which employ simple diffusion through surface membranes (with or without gills) are not greatly harmed. The lack of coleoptera collected at station 187.5 (located below the Bucyrus, Ohio sewage treatment plant) for an 11-month period (figure 3) seems more than enough evidence to support the statements of Brown (1966). The number and kinds of other taxa collected, as well as the chemical parameters, further support the claim that the combined STP of Bucyrus is indeed guilty of soap pollution, a fact that no one seems ready to dispute.

Some coleoptera have surprising cases of survival under other less soapy circumstances. In 1957, Cole reported "that adult female specimen of *Stenelmis crenata* Say survived between 394 and 398 days in a 20 ml shell vial containing 3 ml of water remaining tightly corked". Brown (1973) points out that these "endurance records" suggest the remarkable ability of several kinds of elmids to survive inhospitable conditions and survive in a marginal habitat over surprisingly long periods of time. This hardiness appears to be exhibited almost equally by larval and adult stages. Brown has maintained some larvæ alive in adverse conditions for more than 39 months.

Because (1) these tiny beetles have a potential larva and adult longevity of many years, (2) they can survive environmental extremes (comparable to those occurring in ponds and pools) even though they normally occur in flowing, well - oxygenated streams and, (3) they seem to be drastically affected by soap pollution, aquatic coleoptera could be put to a specific use in water quality monitoring, i.e., detergent or soap pollution detection.

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ABSTRACT

THE ECOLOGY OF RUNNING WATERS; THEROY AND PRACTICE

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A half century of ecological running water research has seen primary concentration on smaller streams and rivers -- lotic ecologists being attracted by greater ease of sampling and lesser influence of man in smaller systems. Although monitoring types of studies on larger rivers have increased as a feature of an enlarged demand for environmental impact staements, basic research and theory remain concentrated in small streams. And yet, the majority of socio-economic problems associated with flowing waters concern the larger rivers.

New studies are evaluating the extrapolation of lotic theory based on first to third order streams to larger (higher order) running waters. Of particular interest is the utilization of information on ecological structural properties and functional relationships of non-perturbated systems in the development of management strategies.

To this end, flowing waters can be generally characterized as given below.

a) Orders 1-3: small headwater springs and streams dominated by their terrestrial setting; heterotrophic -- dependent upon the input of coarse particulate organic matter (CPOM); light and nutrient poor, lesser temperature fluctuation; coarse sediments dominate.
b) Orders 4-6: medium sized rivers dependent less directly on terrestrial inputs; often autotrophic -- dependent upon algal and vascualr aquatic plant production; light and nutrient rich, greater temperature fluctuation; finer sediments.
c) Orders 7-12: large rivers dependent upon the collection of outputs from tributary systems; usually heterotrophic, often with considerable organic loads; light poor (turbid) and nutrient rich, lesser temperature fluctuation; fine sediments dominant.

Paramount to the interfacing of theory and practice is the realization that all running water systems, regardless of size, must be evaluated within overall watershed influences.

THE ECOLOGY OF RUNNING WATERS
THEORY AND PRACTICE

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INTRODUCTION

A half century of ecological research on running waters has seen primary concentration on smaller streams and rivers (first to third order streams; [Leopold et al., 1964])-- lotic ecologists being attracted by greater ease of sampling and a lesser influence of man in smaller systems. Although monitoring types of studies on larger rivers have increased as a feature of enlarged demand for environmental impact assessments, basic research and theory remain concentrated on small streams. And yet, the majority of socio-economic problems associated with flowing waters concern the larger rivers. Therefore, it is important to determine what elements of basic theory developed for smaller streams can be extended to larger rivers and to fashion theoretical constructs for the latter. Paramount to the interfacing of such theory with practice (or management) is the realization that all running water systems, regardless of size, must be evaluated within overall watershed influences.

With only minor exceptions, all running waters fourth order and larger of the 21 major drainage basins (Geraghty et al., 1973) of the United States (excluding Alaska and Hawaii), have been significantly altered --impounded, channelized and polluted. No management strategy can succeed in predictable manipulation or stabilization of stream and river ecosystems unless based upon the fundamental premise that millions of years of organismic evolution (adaptation) and thousands of years of specific habitat acclimatization undoubtedly produced the best fit of biology and environment. In the time of the American Indian, running waters operated efficiently as the product of this prehistory -- all inputs were readily biodegradable, and physical changes due to geological process. Efficiency, as used here, refers to the time course of changes. Streams and rivers operating with biological efficiency do not accumulate organic matter from annual cycle to annual cycle and the constancy of community structure is measured on a time scale of thousands of years.

It seems that the successful manipulation and maintenance of running waters must involve three phases: (1) the identification of key functional processes in a quantitative fashion -- that is development of theory; (2) derivation of rapid and sensitive methods for continued assessment of community status relative to the key functions -- that is monitoring procedures; and, (3) adoption of efficient and responsive procedures for maintaining or re-establishing functional balance -- that is management. Clearly, this is not the package now applied to running water systems.

GENERAL CHARACTERISTICS OF RUNNING WATERS

A general theoretical framework within which running water systems can be viewed should consider such systems as continuua (Vannote, 1975) from headwaters to mouth. Although somewhat imperfect, the stream order system (Leopold et al., 1964; Hynes, 1970; Vannote, 1975) constitutes an initial useful system for physically classifying elements of a drainage system. Other classifications, including ecological criteria, have been formulated (e.g. Pennak, 1971) but a modification of the order system to include channel shape, watershed slope, temperature, discharge and terrestrial input characteristics as well as light regime would seem to have the most potential. To this end, a group of stream ecologists (Cooperative Stream Group) is attempting to formulate such a classification system and to develop (based particularly on Vannote's [1975] continuum theory) a general theoretical construct for running water ecosystems.

Some broad characteristics of running waters clustered into three groupings of stream order are given in Table 1 and depicted diagramatically in Fig. 1. About 85% of all stream miles in the United States are first to third order streams. This immense length of headwater streams (about 2 3/4 million miles; [Leopold et al., 1964; Hynes, 1970; Geraghty et al., 1973]) is intimately interfaced with the bordering terrestrial communities and represents a huge collecting network for the higher order rivers. Due to efficient processing of organic matter by the feeder streams (about 80% for particulate [POM] and 50% for dissolved [DOM] [Fisher and Likens, 1973; Cummins, 1974]) the natural organic loads in larger rivers were, historically, not excessive.

Whereas the miles are in the headwaters, the volume is in the higher orders. The mean daily collective run-off for the drainage system, of which the Sandusky River basin is part, is estimated at 40 billion gallons (Geraghty et al., 1973). At higher stream orders, the direct influence of the adjacent terrestrial communities decreases and the significance of import from upstream increases. Clearly, the successful management of any portion of any river system is a watershed problem.

As shown in Fig. 1, the ecological communities follow a transition from headwaters to higher orders which involves producers (algae and vascular aquatic plants -- vascular hydrophytes), microconsumers (primarily bacteria and fungi) and macroconsumers (invertebrates and fish). Because of the relentless activities of municipalities, industry, agronomists, the Army Corps of Engineers and the Bureau of Reclamation we can only speculate as to the "natural" community structure and function of our larger waterways. An interesting feature of community structure is that the geologically youngest portions of river systems, the headwaters, house the evolutionarily most primitive insects derived from forms of terrestrial origin, while the geologically older sections are inhabited by fewer insects, representing less primitive groups and by invertebrates such as mollusks of marine origin.

The transition in organic inputs and plant growth undoubtedly represents the basis of changing overall community structure and function (Table 1, Fig. 1). The headwaters are characteristically heavily dependent upon terrestrial contributions of particulate organic matter, especially coarse particles (CPOM) such as leaf litter, with little or no photosynthetic production of organic matter in the stream (Fig. 2A, 2B). CPOM feeding invertebrates, or shredders, and detritivores feeding on fine particulate organic matter (FPOM, generally less than 1 mm in diameters), or collectors, are the dominant macroconsumers. Thus the headwaters (orders 1-3) can be described as: CPOM-fungi-shredder-FPOM-bacteria-collector systems.

The intermediate sized rivers (orders 4-6; Fig. 2A, 2C) are less dependent upon direct terrestrial inputs and more on organic production by photosynthesizing algae and vascular hydrophytes along with the input of FPOM from upstream. The ratio of photosynthetic production to community respiration is often greater than one (P/R >1) in contrast to the headwaters above and large rivers below in which respiration exceeds primary production (P/R<1).

Figure 1. A diagrammatic representation of the structure and function in the headwater sections of stream ecosystems. The photosynthetic fixation of carbon into organic compounds upon which the stream depends takes place primarily out of the stream proper on the landscape of the watershed. In such headwater systems algae and vascular hydrophytes contribute minimally to the organic flux of the system. The organisms shown are merely possible representatives of the functional groups that have been identified. (Modified from Cummins, [1974]; see also headwater section of Figure 2.)

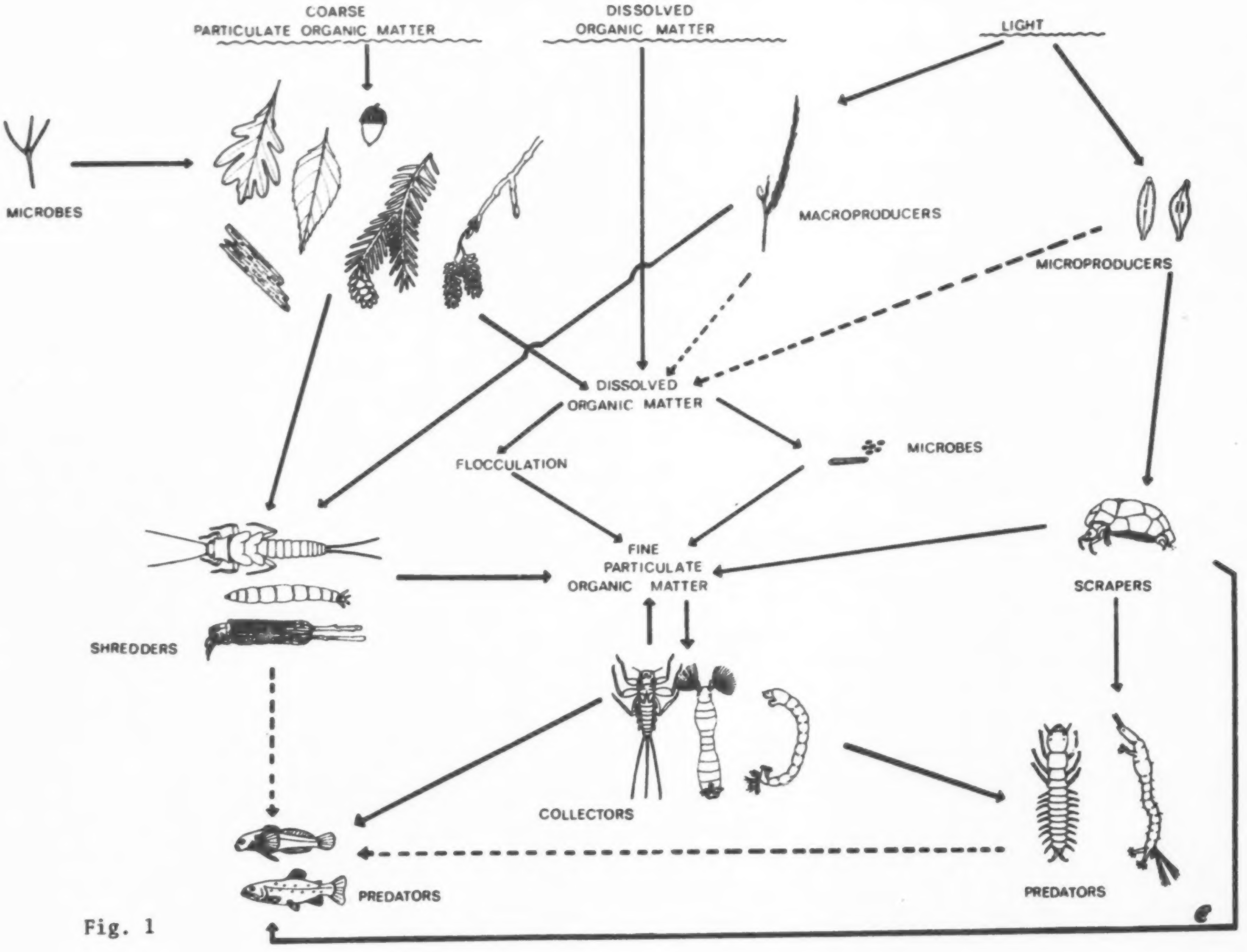
COARSE
PARTICULATE ORGANIC MATTER
DISSOLVED
ORGANIC MATTER
LIGHT
MICROBES
MACROPRODUCERS
MICROPRODUCERS
DISSOLVED
ORGANIC MATTER
FLOCCULATION
MICROBES
FINE
PARTICULATE
ORGANIC MATTER
SHREDDERS
SCRAPERS
COLLECTORS
PREDATORS
PREDATORS

Fig. 1

Table 1. General characteristics of running waters clustered into three stream order groupings.

Stream Orders	Size	Heterotrophy Autotrophy	Organic Matter Inputs of Terrestrial Origin	Primary Production	Light Regime	Temperature Regime	Document Sediments
1-3	Small headwater springs and streams.	Heterotrophic (P/R <1, see Table 2).	Of major importance. Coarse particulate organic matter (CPOM) dominant.	Of minor importance; some algae and mosses.	Heavily shaded.	Lesser daily temperature fluctuation (shading and groundwater effect).	Coarse
4-6	Medium sized rivers.	Autotrophic (P/R >1, (see Table 2).	Of moderate importance. CPOM less significant, fine particulate organic matter (FPOM) from upstream of greater importance	Of major importance; algae and vascular hydrophytes	Little shading, good light penetration.	Greater daily temperature fluctuation (open, less groundwater effect).	Coarse and fine.
7-12	Large rivers.	Heterotrophic (P/R <1, (see Table 2).	Of minor importance. FPOM from upstream dominant	Of moderate to minor importance; primarily planktonic.	Little shading, poor light penetration due to turbidity.	Lesser daily temperature fluctuation (moderation by large volume)	Fine

These intermediate sized running waters can be characterized as: producer-grazer-FPOM-bacteria-collector systems.

The large rivers (orders 7-12; Fig 2A, 2D) tend to be turbid with heavy sediment loads -- the culmination of all the upstream processes. Even before artificial inpoundment, these systems undoubtedly possessed developed plankton communities, although respiration still exceeded photosynthetic production. These rivers could be characterized as: FPOM-bacteria-collector systems.

As shown in Fig. 1, the fish populations generally show a transition from coldwater invertivores, to warm water invertivores and piscivores, to planktivores.

Key Lotic Ecosystem Functions and Management Strategies

A number of parameters that can be measured with relative ease have been shown to be sensitive indicators of critical functional processes in small streams (Cummins, 1974). Most of these (summarized in Table 2) are expressed as ratios. It is assumed that similar measurements in moderate sized and larger rivers would also provide suitable assessments of community function. Once the ranges for the parameters (Table 2) have been determined along non-perturbated river systems (or portions of systems) in different geographical regions (probably minimally the 21 drainage basins given by Geraghty et al. [1973], deviations from generalized theory should be readily discernible and the particular community functions affected identified.

Management strategies developed for a given size range (order) of stream or river should be aimed at restoring community function to a proper balance as assessed by parameters such as those given in Table 2. Aside

Figure 2. A theoretical diagrammatic representation of certain changes in structure function in running water ecosystems from headwater to the mouth (stream order shown at the left). The organisms pictured are merely possible representatives of the functional groups shown (A). The decreasing direct influence of the adjacent terrestrial component of the watershed and increasing importance of upstream import from the headwaters (B, orders 1-3) to the mouth is a basic feature of the system. Coupled with this is a decrease in shredders and an increased dominance of collectors. The mid-region of the river system is seen as the major region of primarily production (growth of green plants) and associated grazer populations (C, orders 4-6). The lower reaches become more turbid with increased importance of plankton (D, orders 7-12). The fishes are dominated by invertivores in the headwaters, and piscivores in the larger sections with planktivores important in the highest order.

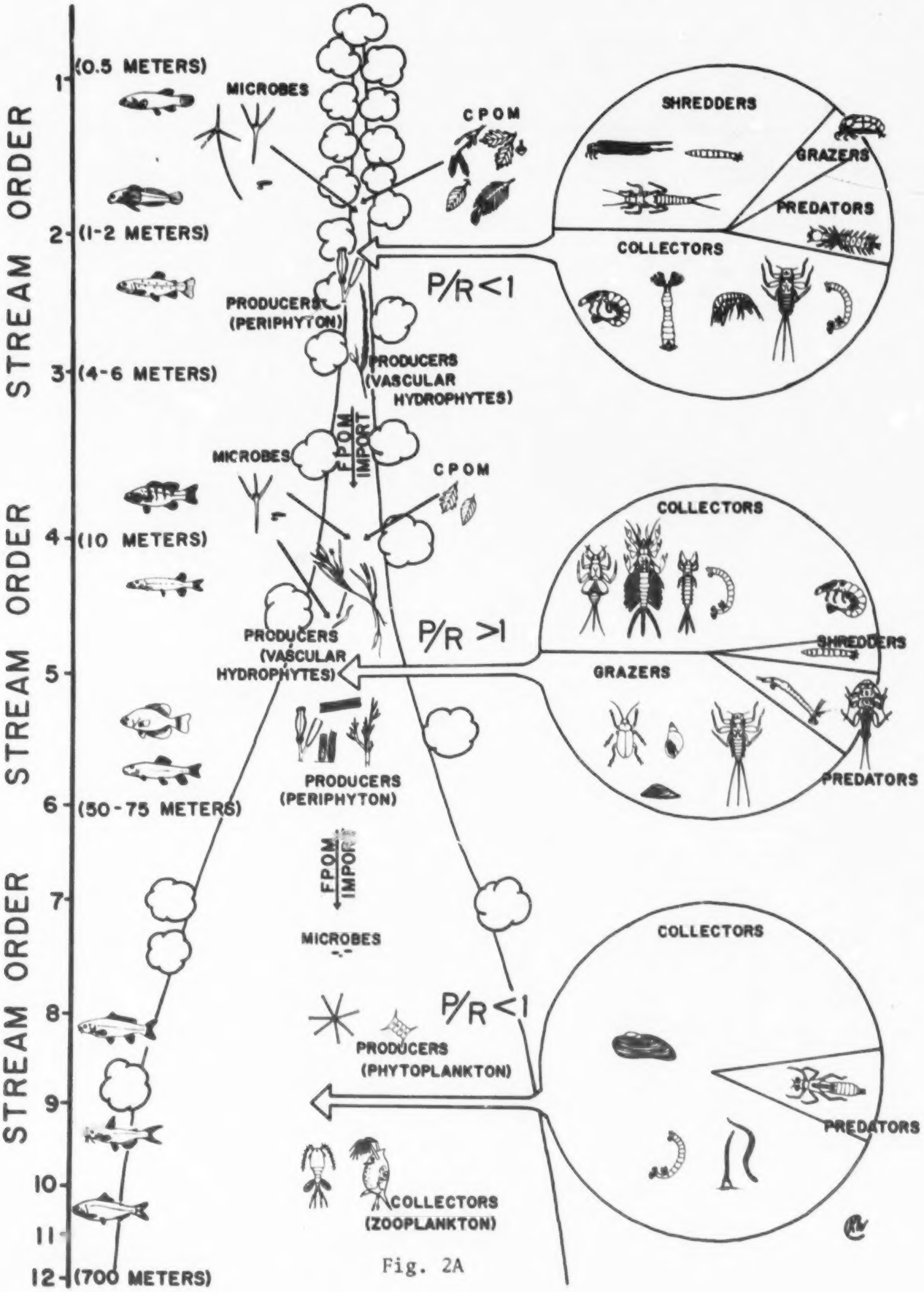
STREAM ORDER
STREAM ORDER
STREAM ORDER
1
(0.5 METERS)
2
(1-2 METERS)
3
(4-6 METERS)
4
(10 METERS)
5
6
(50-75 METERS)
7
8
9
10
11
12
(700 METERS)
MICROBES
CPOM
SHREDDERS
GRAZERS
PREDATORS
COLLECTORS
P/R<1
PRODUCERS
(PERIPHYTON)
PRODUCERS
(VASCULAR
HYDROPHYTES)
FPOM
IMPORT
MICROBES
CPOM
COLLECTORS
P/R >1
SHREDDERS
GRAZERS
PREDATORS
PRODUCERS
(VASCULAR
HYDROPHYTES)
PRODUCERS
(PERIPHYTON)
FPOM
IMPORT
MICROBES
P/R<1
COLLECTORS
PRODUCERS
(PHYTOPLANKTON)
PREDATORS
COLLECTORS
(ZOOPLANKTON)

Fig. 2A

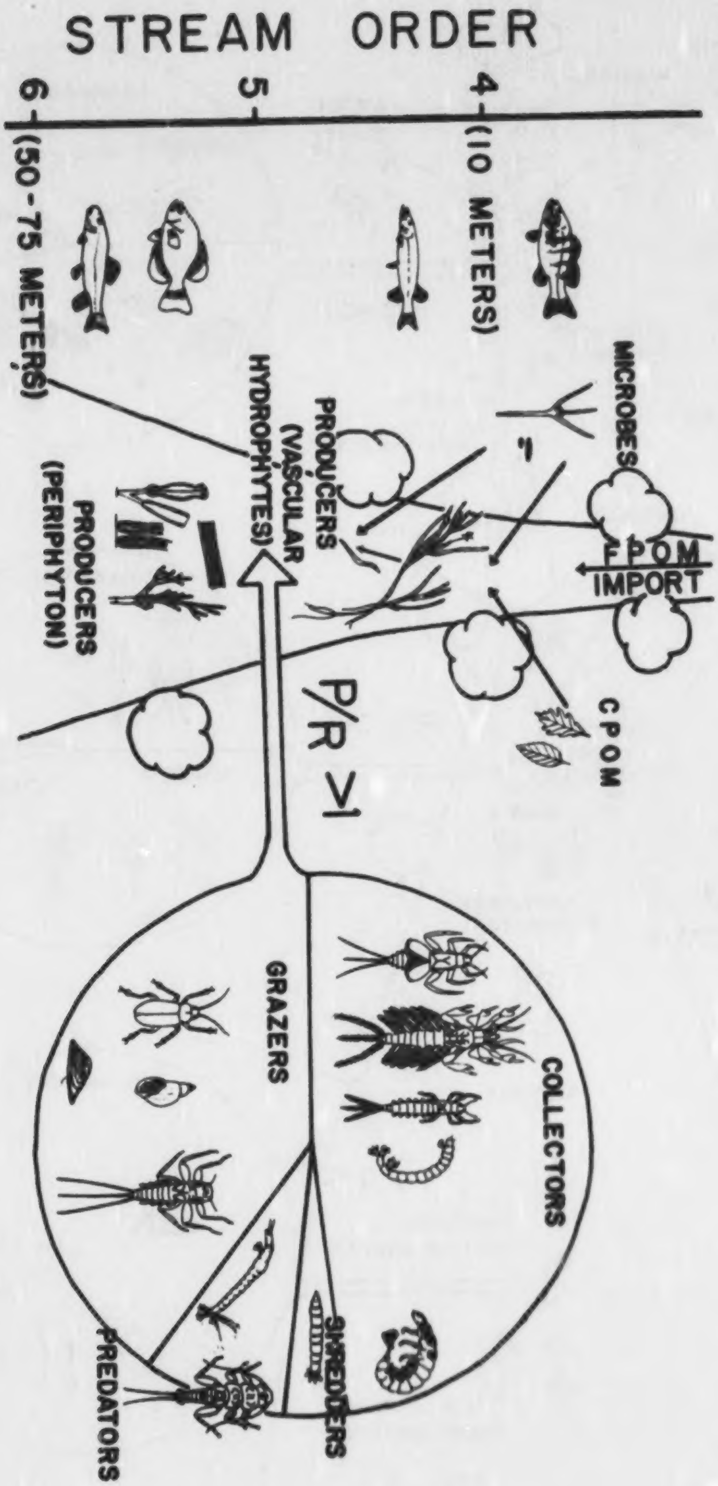
STREAM ORDER
4
5
6
(10 METERS)
(50-75 METERS)
MICROBES
FPOM
IMPORT
CPOM
PRODUCERS (VASCULAR HYDROPHYTES)
PRODUCERS (PERIPHYTON)
P/R >1
COLLECTORS
GRAZERS
SHREDDERS
PREDATORS

Fig. 2C

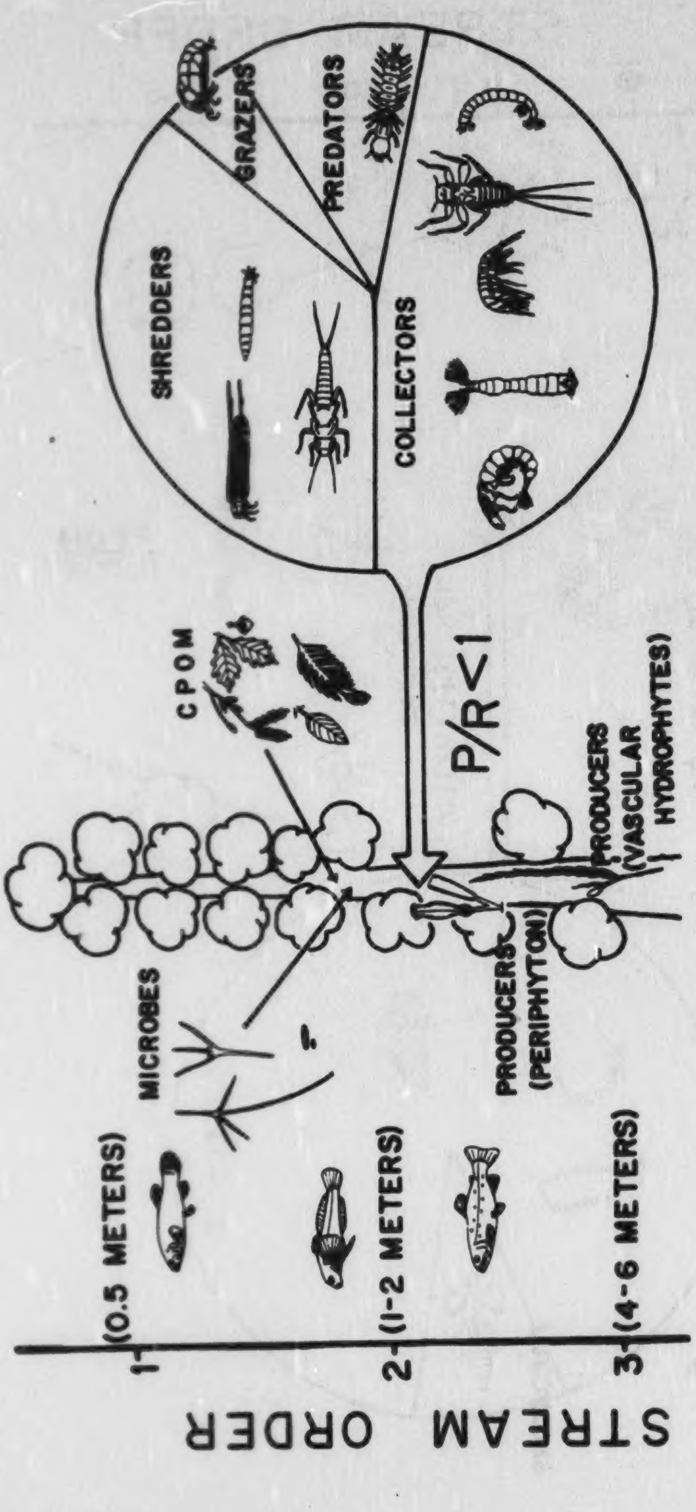
STREAM ORDER
1
(0.5 METERS)
2
(1-2 METERS)
3
(4-6 METERS)
MICROBES
CPOM
PRODUCERS (PERIPHYTON)
PRODUCERS (VASCULAR HYDROPHYTES)
P/R<1
SHREDDERS
GRAZERS
PREDATORS
COLLECTORS

Fig. 2B

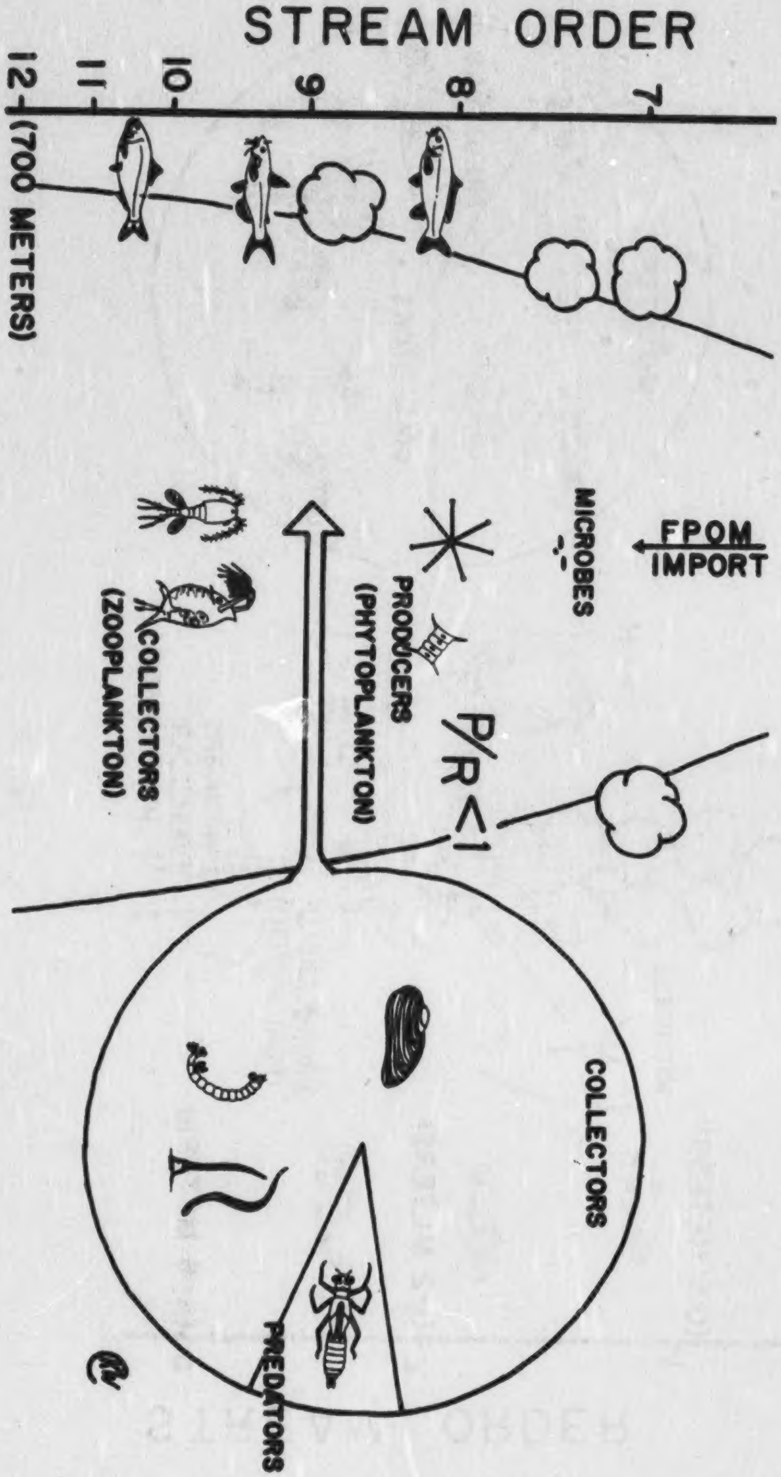
STREAM ORDER
12
11
10
9
8
7
(700 METERS)
FPOM IMPORT
MICROBES
PRODUCERS (PHYTOPLANKTON)
P/R<1
COLLECTORS (ZOOPLANKTON)
COLLECTORS
PREDATORS

Fig. 2D

Table 2. Parameters measured to assess key community functions of running water ecosystems

Parameters (ratio, etc.)	Description	Methods	Interpretation (see Table 1)
P/R	P = gross primary production over 24 hours. R = community respiration over 24 hours.	Measure total oxygen produced (P) and total consumed (R) per 24 hours in circulating or flow through chambers with natural sediments (and water column in large rivers) or upstream-downstream O_2 differences. Seasonal measurements are needed, preferably under a range of light conditions.	P/R >1 predicted only for intermediate sized rivers.
Leaf Litter Processing Rate	Disappearance of leaf litter from experimental packs.	Five or 10 gram leaf packs (Cummins, 1974) removed at intervals, washed, and AFDW determined.	Decreasing processing rates with increasing stream order. Fastest rates in headwaters where P/R <1.
CPOM/FPOM	CPOM = coarse particulate organic matter (>1-4 mm). FPOM = fine particulate organic matter (<1-4 mm).	Assess for both the sediment and transport systems (bottom and drift samples) expressed as ash free dry wt (AFDW)	CPOM/FPOM >0.25-0.50 in head waters, decreasing with increasing stream order.
Shredders/Collectors	Shredders = detritivores feeding on microbially colonized CPOM. Collectors = detritivores feeding on microbially colonized FPOM.	Measure animal biomass, separated into shredders and collectors (Cummins, 1973), removed from leaf packs and/or CPOM/FPOM samples.	Shredders/Collectors is maximum in headwaters; highes when leaf pack processing is greatest and P/R <1.
Grazers/Detritivores	Grazers = algal and vascular hydrophyte (living photosynthetic tissue) feeders. Detritivores = shredders + collectors.	Measure animal biomass, separated into grazers and detritivores (Cummins, 1973), from leaf packs and bottom sediment samples.	Grazers/Detritivores is maximum when P/R >1.
C/N	C = carbon N = nitrogen	Determine C/N ratio on detritus samples (sediment and transport) using C, N, H analyzer	C/N decreases when microbial colonization of detritus is maximum

from the problem of substances that are directly toxic, manipulation should be possible particularly with regard to such features as the ratio of gross photosynthesis and respiration and the particle size distribution of organic detritus. For example, in smaller streams maintenance of shading vegetation and entrainment structures for CPOM (especially leaf litter) should be used to insure maximum processing in upstream tributaries. The addition of any man-engendered organics must be viewed in the context of natural inputs. Since there is an ever increasing influence on upstream import as stream order increases, such management practices in the headwaters should be of very considerable importance.

As stated previously, the thrust of successful management strategies will certainly be to maintain or re-establish those key community functions which, through evolutionary adaption, established efficient interfaces between our running waters and their terrestrial settings. This is a time for difficult reassessments if a watershed is to be restored and preserved to most closely resemble its former functional efficiency as it appeared before the tamperings of "civilized" man. Among the heretofore basic assumptions that must be re-examined are the suitability of present agricultural practices and population expansion. Must energetically inefficient agriculture and population-growth stimulated development occur in all watersheds? Once the actual costs involved have been accurately assessed, which has yet to be accomplished in any watershed, such apparently difficult reassessments should be significantly facilitated.

Acknowledgments

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ABSTRACT

AQUATIC VASCULAR PLANTS OF THE SANDUSKY RIVER BASIN

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Botanically speaking, little has been written on the vascular flora of the Sandusky River Basin, and of what has been written, more is probably known of the plants of the wetlands than any other vegetation type. The wetlands consist of (1) the remnants of original wet prairies, marshes, swamps, peat lands, and cranberry bogs in the upper portion of the Basin, (2) the once vast and extensive, but now contained, diked marshes at the upper end of Sandusky Bay, (3) the Sandusky River and its tributaries, and (4) the man-created drainage ditches, reservoirs, and farm and recreation ponds. Approximately 240 species of aquatic vascular plants are presently known from aquatic habitats in the Basin. Of these, 58 (24%) are common and widespread in many localities, 84(35%) are occasional and scattered in few localities, 68 (28%) are rare and known mostly from one or two localities, and 30 (13%) are believed to be extirpated.

The extirpated species have been determined from records taken in earlier floristic surveys compared with records obtained within the past ten years. In the remnant wetlands in the upper portion of the Basin, many portions have been drained for agricultural purposes. The soil and peat deposits have become dry, permitting repeated muck fires. These two situations are major factors that have brought about the extirpation of rare northern bog species in these wetlands. At Sandusky Bay, diking of the marshes and the increased turbidity of the water, resulting from this operation and from soil runoff of the once forested uplands, are the major factors for the loss of submersed aquatic species that normally grow in clear waters.

The Sandusky River and some of its tributaries also contain many of the aquatic species that occur in the wetlands previously described. A few southern, mudflat or shallow water species, not found elsewhere in the Basin, add distinction to the flora. Submersed species are generally absent because of the turbidity of the water and the silted bottom conditions. The man-created ditches, reservoirs, and ponds have an invading aquatic flora, but the species composition of these aquatic habitats is virtually unknown and in need of a thorough study.

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AQUATIC VASCULAR PLANTS OF THE SANDUSKY RIVER BASIN[1]

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Little has been written on the vascular-plant flora of the Sandusky River Basin. No studies of the original vegetation or lists of vascular plants have been prepared for any large area or county within the Basin. Of what little has been written, more deals with the vegetation of the wetlands than with the drier forested or cultivated areas.

HISTORICAL REVIEW

One of the earlier descriptions of the original vegetation was recorded in 1757 by Colonel James Smith (1799, p. 49). He wrote:

> From the mouth of the Sandusky to the falls [at Fremont, Ohio] is chiefly first rate land, lying flat or level, intermixed with large bodies of clear meadows, where the grass is exceedingly rank, and in many places three or four feet high. The timber is oak, hickory, walnut, cherry, black-ash, elm, sugar-tree, buckeye, locust, and beech. In some places there is wet timber land--the timber in these places is chiefly water-ash, sycamore, or button-wood.
>
> From the falls to the prairies, the land lies well to the sun, it is neither too flat nor too hilly--and chiefly first rate. The timber near the same as below the falls, excepting the water-ash. There is also here, some plats of beech land, that appears to be second rate, as it frequently produces spice-wood. The prairie appears to be a tolerable fertile soil, tho in many places too wet

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[1] Contribution from the Department of Botany (Paper No. 890), the Herbarium, the Franz Theodore Stone Laboratory, and the Center for Lake Area Research of The Ohio State University,

for cultivation; yet I apprehend it would produce timber, were it only kept from fire.

In describing the vegetation of the lower portion of the Sandusky, below Fremont, Samuel R. Brown (1815, pp. 133-135) wrote that the first ten miles was principally "oak with little under-wood," the swales were covered with "lynn, sugar maple, honey locust, cucumber, red elm, &c," and the open areas, or prairies, were always surrounded by "fine oak and chestnut land."

In 1836, John Leonard Riddell, a botanist and author of the first flora west of the Allegheny Mountains (Riddell, "1834" [1835]), traveled in horse and buggy from Kenton to Upper Sandusky and followed the river valley through McCutchenville, Tiffin, Fremont to Port Clinton. His travels were made as a contribution to the First Geological Survey of Ohio. Although primarily an account of the geological features of the region, Riddell (1837) described the woody vegetation and listed some of the trees. The trees were those he saw along the Broken Sword Creek while on a separate excursion from Upper Sandusky. He also briefly commented upon the wet prairies around Sandusky Bay. His lists of herbaceous plants of the Sandusky Plains and of a cranberry bog north of Upper Sandusky remain in manuscript (Riddell, 1836).

As stated by Keeler (1904, p. 195), "except where the 'plains' smiled to the sun in grass and flowers the Sandusky country was densely wooded. Great oaks, elms, walnuts and hickories were interspersed with beech, basswood, maple and sycamore." We may suspect that the river was rich with aquatic plants because Keeler (1904, p. 193) noted that the Wyandot Indian word "Sandustee," meaning "water-within-the-water-pools," is a description particularly applicable to Sandusky Bay and that portion of the river below Fremont where there were extensive marshes intersected in many directions by pools and channels of open water.

The peat deposits of the Sandusky River Basin were surveyed by a later botanist, Alfred Dachnowski (1912). In his report the character of the vegetation, plant communities, and names of selected distinctive species were given for several of the more prominent original wetlands. Bonser (1903) prepared the only detailed floristic account of a specific wetland in the upper portion of the Basin. His paper described the vegetation and listed many of the species of the Big Spring Prairie, a calcareous wet meadow, or fen, at the junction of Wyandot, Hancock and Seneca counties. Certain distinctive alkaline bog-meadow species that are found nowhere else in the Basin were reported from this wetland. However, because much of this wet prairie drains into the Blanchard River, the detailed results and significance of Bonser's paper are not discussed further. The remnant peat bogs of Crawford County have been sampled for pollen, and interpretations of the post-glacial forest sequence and glacial climate have been made by Sears (1930), Gersbacher (1939), and Potter (1946, 1947). Using the records of the witness trees as recorded in detail in the original land surveys, Paul B. Sears developed methods to map the original vegetation of Ohio. Using the data from the surveys in Crawford and Wyandot counties, he pointed out that the wet prairie-oak-hickory was in areas lacking any organized drainage, whereas beech-maple grew in those areas where drainage was well-developed (Sears, 1926). Subsequently, the original vegetation as interpreted from the earliest land surveys has been depicted on a map of the original vegetation of Ohio by Gordon (1966).

With respect to Sandusky Bay, the aquatic vascular plants were initially. listed in the now classic Sandusky Flora by Edwin Lincoln Mosely (1899). Adrian J. Pieters (1901) also listed aquatic vascular plants of the upper portion of Sandusky Bay and briefly described the condition of the vegetation.

More recently, Lowden (1967, 1969) published a vascular plant flora of Winous Point at the upper end of Sandusky Bay. His study is significant because of the discussion of the changes in aquatic flora from the time of Moseley's and Pieter's surveys compared to the present situation. Additional information on the aquatic vascular plants of Sandusky Bay can be found in Burr (1901), Moseley (1905), and Meeks (1963, 1969).

With respect to the Sandusky River itself, particularly above Fremont, no reports on the aquatic plants have ever been prepared. Brief mention of a few aquatic plants is made in a biological survey of one of the tributaries, Sycamore Creek (Volk, 1941). No floristic surveys have been published on man-created aquatic habitats, such as drainage ditches, reservoirs, and farm and recreation ponds. Current distributional records of many individual species mapped by county can be found in Braun (1961, 1967) and in various papers published on the Ohio flora in the Ohio Journal of Science and Castanea during the past 15 years.

WETLANDS OF THE BASIN

The aquatic areas or wetlands of the Sandusky River Basin may be grouped into four categories: (1) the remnants of original wet prairie, marshes, swamps, peat lands, and cranberry bogs in the upper portion of the Basin; (2) the once vast and extensive, but now contained, diked marshes at the upper end of Sandusky Bay; (3) the Sandusky River and its tributaries; and (4) the man-created drainage ditches, reservoirs, and farm and recreation ponds. This paper reviews the previous reports on the aquatic flora of the Basin as a baseline for evaluating my field research conducted in many of these aquatic habitats in the Basin over the past 15 years. The most extensive field research was accomplished during the summer and fall of 1967, 1968, and 1969. My field records supplemented with those records from preserved herbarium specimens in the Ohio State University Herbarium provide the data for the annotated list of the aquatic vascular plants of the Basin (table 1). Approximately 240 species of aquatic vascular plants are now known from the Basin. Of these, 58 (24%) are common and widespread in many localities; 84 (35%) are occasional and scattered in few localities; 68 (28%) are rare and known mostly from one or two localities; and 30 (13%) are believed to be extirpated.

Remnant Original Wetlands in the Upper Portion of the Basin

In the upper portion of the Sandusky River Basin, original extensive wetlands developed in shallow lakes that filled with vegetation in many of the low areas between moraines that were left by the retreating Wisconsin glacier some 13,500 years ago. All of these wetlands lay to the south of the oldest of the ancient Lake Erie beach ridges, Lake Maumee, which forms a line from Fostoria, east to Tiffin, and north to Clyde. The most extensive of these original wetlands is mapped here (fig. 1) as they were outlined on maps made in the early 1800's by the original land surveyors in the Basin. At times, the surveyors distinguished between wet prairie, swamp, marsh, and cranberry bog. However, these distinctions cannot always be made after seeing what remnants remain today and from evaluating the descriptions of these wet areas in county history books, such as those by Perrin, Battle, and Goodspeed (1888, pp. 179, 510, 624, 627-678, 651-652, 677), Lesson (1886, p. 536) , Schenck (1884, p. 215), and from other sources, for example, Anonymous (1824), Niles (1864), and Dachnowski (1912, pp. 46, 75, 80-84, 114-116, 143-144, 233, 238-289, 258). Most of the wetlands in Crawford County were mapped as swamps, having woody vegetation; whereas those of Wyandot County

Table 1: Annotated list of aquatic vascular plants of the Sandusky River Basin based on specimens in The Ohio State University Herbarium and on records compiled during field surveys by Ronald L. Stuckey, especially during the 1967, 1968, and 1969 field seasons.

Species[a]	Abundance[b]	Localities[c]
EQUISETACEAE		
Equisetum hyemale L. Scouring-rush.	Common	. S . .
OSMUNDACEAE		
Osmunda cinnamomea L. Cinnamon Fern.	Rare	. . W .
Osmunda regalis L. Royal Fern.	Rare	. . W .
ASPIDIACEAE		
Onoclea sensibilis L. Sensitive Fern.	Occasional	B . W .
Thelypteris palustris (Salisb.) Schott var. *pubescens* Fern. Marsh Fern.	Occasional	. . W .
SALVINIACEAE		
Azolla caroliniana Willd. Water-velvet.	Rare	B . . .
TYPHACEAE		
Typha angustifolia L. Narrow-leaved Cat-tail.	Common	B . . A
Typha latifolia L. Broad-leaved Cat-tail, Common Cat-tail.	Common	B S W A

SPARGANIACEAE		
Sparganium eurycarpum Engelm. Bur-reed.	Occasional	B S W A
POTAMOGETONACEAE		
**Potamogeton crispus* L. Curly Pondweed.	Occasional	B . . A
Potamogeton foliosus Raf. Leafy Pondweed.	Common	B . . A
Potamogeton nodosus Poir. Knotty Pondweed.	Occasional	B S . .
Potamogeton pectinatus L. Sago Pondweed.	Occasional	B . . A
Potamogeton pusillus L. Small Pondweed.	Occasional	. . . A
NAJADACEAE		
Najas guadalupensis (Spreng.) Magnus Naiad.	Occasional	. . . A
**Najas minor* All. Naiad.	Rare	B . . A
ALISMACEAE		
Alisma plantago-aquatica L. Water-plantain.	Common	B S W A
Lophotocarpus calycinus (Engelm.) J. G. Smith	Rare	B . . .
Sagittaria latifolia Willd. Arrowhead.	Common	B S W A
Sagittaria rigida Pursh. Stiff Arrowhead.	Rare	B . . .
BUTOMACEAE		
**Butomus umbellatus* L. Flowering-rush.	Rare	B . . .

HYDROCHARITACEAE

Elodea canadensis Michx. Waterweed.	Occasional	. . . A
Elodea nuttallii (Planch.) St. John Waterweed.	Rare	B . . A

GRAMINEAE

Alopecurus aequalis Sobol. Foxtail.	Rare	B . . .
Calamagrostis canadensis (Michx.) Nutt. Blue-joint Grass.	Occasional	B . . A
**Echinochloa crusgalli* (L.)Beauv. Barnyard Grass.	Common	B S W A
Echinochloa pungens (Poir.) Rydb. Barnyard Grass.	Common	B S W A
**Echinochloa walteri (Pursh)* Nash Watler's Millet.	Rare	B . . .
Elymus virginicus L. Virginia Wild Rye.	Common	. S W A
Eragrostis frankii C.A. Meyer Love Grass.	Common	. . . A
Eragrostis hypnoides (Lam.) BSP. Love Grass.	Occasional	B S . .
Glyceria grandis S. Wats. Reed-meadow Grass.	Rare	. . . A
Glyceria striata (Lam.) Hitchc. Fowl-meadow Grass.	Common	B . W .
Glyceria septentrionalis Hitchc. Floating Manna Grass.	Rare	. . . A
Leersia oryzoides (L.) Swartz Rice Cut Grass.	Common	B S W A

Panicum capillare L. Old-witch Grass.	Common	B . . A
Panicum dichotomiflorum Michx. Panic Grass.	Common	B . . A
Phalaris arundinacea L. Reed Canary Grass.	Occasional	B S W A
Phragmites australis (Cav.) Trin. ex. Steud. *(P. communis* Trin.*)* Reed Grass.	Rare	B . . .
Spartina pectinata Link. Cord Grass.	Occasional	B S . A
Zizania aquatica L. Wild Rice.	Rare	B . . .

CYPERACEAE

Carex aquatilis Wahlenb.	Rare	B . . .
Carex atherodes Spreng.	Occasional	B . . .
Carex comosa Boott	Occasional	B . W .
Carex crinita Lam.	Occasional	. . W A
Carex cristatella Britt.	Occasional	B . . .
Carex frankii Kunth	Occasional	B S . A
Carex granularis Muhl.	Rare	B . . .
Carex hyalinolepis Steud.	Occasional	. S . .
Carex hystricina Muhl.	Rare	B . . .
Carex lacustris Willd. Ripgut.	Occasional	B . W .
Carex lanuginosa Michx.	Rare	B . . .
Carex lupulina Muhl.	Occasional	. . W A
Carex lurida Wahlenb.	Occasional	. . W A
Carex muskingumensis Schwein.	Occasional	. . W A

Carex stipata Muhl.	Common	B . . A
Carex tribuloides Wahlenb.	Rare	B . W .
Carex vesicaria L.	Rare	. . W .
Carex vulpinoidea Michx.	Common	B . W A
Cyperus diandrus Torr.	Rare	B . . .
Cyperus engelmannii Steud	Rare	B . . .
Cyperus erythrorhizos Muhl. Umbrella Sedge.	Occasional	B S . .
Cyperus esculentus L. Yellow Nut-grass.	Common	B S W A
Cyperus ferruginescens Boeckl. *(C. odoratus* L.*)* Umbrella Sedge.	Common	B S W A
Cyperus inflexus Muhl.	Rare	. S . .
Cyperus rivularis Kunth	Occasional	B S . .
Cyperus strigosus L. Nut-grass	Common	B S W A
Eleocharis acicularis (L.) R. & S. Needlerush.	Occasional	B . W .
Eleocharis erythropoda Steud. *(E. calva* Torr.*)* Spike-rush.	Occasional	B S . .
*Eleocharis intermedia (*Muhl.*)* Schultes Spike-rush.	Rare	B . . .
*Eleocharis obtusa (*Willd.*)* Schultes Spike-rush.	Common	B . W A
Eleocharis smallii Britt. Spike-rush.	Rare	B . W .
Scirpus acutus Muhl. Hard-stem Bulrush.	Rare	B . . .
Scirpus atrovirens Willd. Dark-green Bulrush.	Common	B S W A

Scirpus atrovirens Willd. *X S. georgianus*	Rare	. . W .
Scirpus cyperinus (L.) Kunth Wool-rush.	Occasional	B . W .
*Scirpus fluviatilis (*Torr.*)* Gray River Bulrush.	Occasional	B . . .
Scirpus georgianus Harp.	Rare	. . W .
Scirpus hattorianus Mak.	Rare	. . W .
Sicrpus pedicellatus Fern.	Rare	. . W .
Scirpus pendulus Muhl. *(S. lineatus* Michx.*)*	Rare	B . . A
Scirpus polyphyllus Vahl	Rare	. . W .
Scirpus pungens Vahl *(S. americanus* Pers.*)* Three-square.	Occasional	B S . .
Scirpus validus Muhl. *var. creber* Fern. Soft-stem Bulrush.	Common	B . W A

ARACEAE

Acorus americanus Raf. *(A. calamus* L.*)* Sweetflag.	Rare	. . W .

LEMNACEAE

Lemna minor L. Lesser Duckweed.	Common	B . . A
Lemna trisulca L. Star Duckweed.	Common	B . . A
Spirodela polyrhiza (L.) Schleid Greater Duckweed.	Common	B . . A
Wolffia columbiana Karst. Water-meal.	Rare	B . . A
Wolffia punctata Griseb. Water-meal.	Rare	B . . A

PONTEDERIACEAE

Heteranthera dubia (Jacq.) MacN. Water Stargrass.	Rare	B . . .
Pontederia cordata L. Pickerelweed.	Rare	B . . .

JUNCACEAE

Juncus acuminatus Michx. Rush.	Occasional	. . W .
Juncus canadensis J. Gay Canadian Rush.	Rare	. . W .
Juncus dudleyi Wieg. Dudley's Rush.	Occasional	B S . .
Juncus effusus L. Soft Rush.	Common	. . W A
Juncus interior Wieg.	Rare	. . . A
Juncus tenuis Willd. Path Rush.	Common	B S W A
Juncus torreyi Coville Torrey's Rush.	Occasional	B . . A

IRIDACEAE

**Iris pseudacorus* L. Yellow Iris.	Rare	. . . A
Iris virginica L. var. shrevei (Small) E. Anders. *Iris*. Blue Flag.	Occasional	B . W .

SAURURACEAE

Saururus cernuus L. Lizard's Tail.	Occasional	. S . .

SALICACEAE

Populus deltoides Bartr. Cottonwood.	Common	B S W A
**Salix alba* L. White Willow.	Occasional	B . . A
Salix amygdaloides Anderss. Peach-leaved Willow.	Occasional	B S . .

******Salix fragilis*** L. Crack Willow.**	**Common**	**B . . A**
Salix interior **Rowlee Sandbar Willow.**	**Common**	**B S . A**
Salix nigra **Marsh. Black Willow.**	**Common**	**B S W .**
Salix rigida **Muhl.Stiff Willow.**	**Rare**	**B . . .**

URTICACEAE

Boehmeria cylindrica **(L.) Sw. False-Nettle.**	**Common**	**B S W .**
Laportea canadensis **(L.) Wedd. Wood-Nettle.**	**Common**	**. S W .**
Pilea pumila **(L.) Gray Clearweed.**	**Common**	**B S . .**
******Urtica dioica*** L. Stinging Nettle.**	**Common**	**. S W A**
Urtica procera **Muhl. Nettle.**	**Common**	**B . W A**

POLYGONACEAE

Polygonum amphibium **L. var.** ***stipulaceum*** **Colem.** ***(P. amphibium*** **L.)** **Water Smartweed.**	**Occasional**	**. . . A**
Polygonum amphibium **L. var.** ***emersum*** **Michx.** ***(P. coccineum*** **Muhl.)** **Water Smartweed.**	**Common**	**B . W .**
******Polygonum hydropiper*** L. Water-pepper.**	**Occasional**	**B S W A**
Polygonum hydropiperoides **Michx. Mild Water-pepper.**	**Occasional**	**. . . A**
Polygonum lapathifolium **L. Dock-leaved Smartweed.**	**Occasional**	**B S W A**

Polygonum pensylvanicum L. Pinkweed.	Common	B S W A
**Polygonum persicaria* L. Lady's thumb.	Common	B S W A
Polygonum punctatum Ell. Water Smartweed.	Common	B S W A
Polygonum sagittatum L. Arrow-leaved Tearthumb.	Occasional	B . W A
Rumex altissimus Wood Pale Dock.	Occasional	. S . .
**Rumex martimus* L. var. *fueginus* (Phil.) Dusen Golden Dock.	Rare	B . . .
Rumex orbiculatus Gray Great Water Dock.	Rare	B . . .
Rumex verticillatus L. Swamp Dock.	Occasional	B S W .

AMARANTHACEAE

Amaranthus tuberculatus (.) *Sauer* Water-hemp.	Occasional	B S W .

NYMPHACEAE

Nelumbo lutea (.) . American Lotus, Yellow Nelumbo.	Rare	B . . .
Nuphar advena Ait. Spatter-dock.	Occasional	B . . A
Nuphar variegatum Englem. Spatter-dock.	Rare	B . . .
Nymphaea tuberosa Paine White Water-lily.	Rare	B . . .

CERATOPHYLIACEAE

Ceratophyllum demersum L. Hornwort, Coon-tail.	Common	B . . A

RANUNCULACEAE

Caltha palustris L. Marsh-marigold.	Occasional	. . W .

Ranunculus flabellaris Raf. Yellow Water Buttercup.	Rare	. . W .
Ranunculus pensylvanicus L. f. Bristly Crowfoot.	Rare	B . W .
Ranunculus septentrionalis Poir. Swamp Buttercup.	Common	B . W .
Ranunculus sceleratus L. Cursed Crowfoot.	Occasional	B S W A

CRUCIFERAE

**Armoracia rusticana* (Lam.) Gaertn., Mey. and Schreb. Horseradish.	Rare	. . . A
Cardamine bulbosa (Muhl.) BSP. Bitter Cress.	Common	. . W .
Cardamine pensylvanica Muhl. Pennsylvania Bitter Cress.	Common	B S W .
Rorippa palustris (L.) Bess. var. *fernaldiana* (Butt. & Abbe) Stuckey Marsh Cress.	Occasional	B S W A
Rorippa palustris (L.) Bess. var. *hispida* (Desv.) Rydb. Marsh Cress.	Rare	B . . .
**Rorippa sylvestris* (L.) Bess. Creeping Yellow Cress.	Occasional	B S . .

SAXIFRAGACEAE

Penthorum sedoides L. Ditch Stonecrop.	Occasional	B S W A

ROSACEAE		
Rosa palustris Marsh. Swamp Rose.	Occasional	B . W .
Spiraea alba DuRoi Meadow-sweet.	Occasional	. . W .
LEGUMINOSAE		
Strophostyles helvola (L.) Ell. Wild Bean.	Rare	B . . .
ANACARDIACEAE		
Rhus vernix L. Poison Sumac.	Rare	. . W .
AQUIFOLIACEAE		
Ilex verticillata (L.) Gray Winterberry, Black Alder.	Rare	. . W .
MALVACEAE		
Hibiscus moscheutos L. *(H. palustris* L.*)* Swamp-Rose Mallow.	Rare	B . . A
GUTTIFERAE		
*Hypericum boreale (*Britt.*)* Bickn. St. John's Wort.	Occasional	. . W A
Hypericum mutilum L. St. John's Wort.	Occasional	. . W A
LYTHRACEAE		
Ammannia coccinea Rothb. Ammannia.	Rare	B . . .

Decodon verticillatus (L.) Ell. Swamp-Loosestrife.	Rare	B . W .
Lythrum dacotanum Nieuw. *(L. alatum* Pursh*)* Loosestrife.	Occasional	B S . .
**Lythrum salicaria* L. Spiked Loosestrife.	Rare	B S . A
ONAGRACEAE		
Epilobium glandulosum Lehm. Willow-herb.	Occasional	B S W A
Ludwigia alternifolia L. Seedbox.	Rare	. . W .
Ludwigia palustris (L.) Ell. var. *americana (*DC.*)* Fern. & Grisc. Water purslane.	Occasional	B S W A
Ludwigia polycarpa Short & Peter	Rare	B S . .
HALORAGACEAE		
**Myriophyllum spicatum* L. Water-milfoil.	Occasional	B . . A
Myriophyllum exalbescens Fern. Water-milfoil.	Rare	B . . .
UMBELLIFERAE		
Cicuta bulbifera L. Water-hemlock.	Occasional	B . W .
Cicuta maculata L. Spotted Water-hemlock.	Occasional	B . W .
Sium suave Walt. Water-parsnip.	Occasional	. . W .
PRIMULACEAE		
Lysimachia ciliata L. Loosestrife.	Occasional	B S W A

**Lysimachia nummularia* L. Moneywort.	Occasional	B S . A
Lysimachia quadriflora Sims Whorled Loosestrife.	Rare	. S . .
Lysimachia terrestris (L.) BSP. Swamp Loosestrife.	Rare	. . W .
Lysimachia thyrsiflora L. Tufted Loosestrife.	Rare	B . W .
Samolus parviflorus Raf. Water-pimpernel.	Occasional	B S . .

ASCLEPIADACEAE

Asclepias incarnata L. Swamp Milkweed.	Common	B S W A

VERBENACEAE

Phyla lanceolata Greene *(Lippia lanceolata* Michx.*)* Fog Fruit.	Occasional	B S . .
Verbena hastata L. Blue Vervain.	Common	B S W A
Verbena urticifolia L. White Vervain.	Common	B S . A

LABIATAE

Lycopus americanus Muhl. Water Horehound.	Common	B S W A
Lycopus rubellus Moench	Rare	. S . .
Lycopus x sherardi Steele	Occasional	. S . .
Lycopus uniflorus Michx. Water Horehound.	Occasional	B . W .
Mentha arvensis L. Mint.	Common	B S . A
Physostegia virginiana (L.) Benth. False Dragonhead.	Occasional	B S . .

Scutellaria lateriflora L. Mad-dog Skullcap.	Common	B S W .
Scutellaria epilobiifolia A. Hamilton Common Skullcap.	Occasional	B . W .
Stachys tenuifolia Willd. Hedge-nettle.	Occasional	B S W .
Stachys palustris L. Woundwort.	Occasional	. . W .
SOLANACEAE		
**Solanum dulcamara* L. Bittersweet Nightshade.	Common	B S W A
**Solanum nigrum* L. Black Nightshade.	Common	B S . A
SCROPHULARIACEAE		
Lindernia dubia (L.) False Pimpernel.	Occasional	B S . A
Mimulus ringens L. Monkey Flower.	Occasional	B . W A
Veronica comosa Richter Water Speedwell.	Rare	. . W .
LENTIBULARIACEAE		
Utricularia vulgaris L. Bladderwort.	Occasional	B . . .
RUBIACEAE		
Cephalanthus occidentalis L. Buttonbush.	Common	B S W .
CAPRIFOLIACEAE		
Sambucus canadensis L. Elderberry.	Common	B . W A

CUCURBITACEAE		
Echinocystis lobata (Michx.) T. & G. Prickly-cucumber.	Occasional	B S . .
Sicyos angulatus L. Bur-cucumber.	Occasional	B S . .
CAMPANULACEAE		
Lobelia cardinalis L. Cardinal Flower.	Rare	. . W .
Lobelia syphilitica L.Great Lobelia.	Occasional	. S . A
COMPOSITAE		
Boltonia asteroides (L.) L'Her . Boltonia.	Rare	B . . .
Eupatorium maculatum L. Joe-pye-weed.	Occasional	. S . .
Eupatorium perfoliatum L. Boneset.	Common	B S W A
Bidens cernuus L. Nodding Stick-tight.	Common	B S W A
Bidens comosus (Gray) Wieg. Begger-ticks.	Occasional	B . W .
Bidens coronatus (L.) Britt. Tickseed.	Occasional	. . W .
Bidens frondosus L. Beggar-ticks.	Common	B S W A
Bidens polylepis Blake	Rare	. . . A
Bidens vulgatus Greene Beggar-ticks.	Occasional	. . . A
Eclipta alba (L.) Hassk. Yerba-de-tago.	Occasional	B S . .
Helenium autumnale L. Sneezeweed.	Occasional	B S . .
**Xanthium strumarium* L. Cocklebur.	Common	B S . A

Footnotes to Table 1

[a] Scientific names are based on and arranged in the sequence of Fernald (1950), except in certain cases where names are included as used in recent monographs or revisions, then the names from Fernald may be given in parentheses. Those species marked with an asterisk (*) are considered to be non-indigenous to the Sandusky River Basin. Species of the genus *Cornus* and *Galium*, which occur in wetlands in the Basin, have not been studied and are not included in this list.

[b] Key to abundance categories:

Common - Widespread in many localities.
Occasional - Scattered in few localities.
Rare - Known mostly from one or two localities.
Extirpated - Believed no longer to be growing in the Basin.

[c] Key to localities:

B - Sandusky Bay. Records taken from (Lowden, 1969) plus some additional records by Ronald L. Stuckey.
S - Sandusky River
W - "Natural" remnant wetlands, e.g., marshes, swamps, and former cranberry bogs.
A - "Artificial" newly-created wetlands, e.g., ditches, reservoirs, and ponds.

were mapped as wet prairie, having herbaceous vegetation. Without making any distinctions, the most extensive of these original wetlands are shown by the shaded areas in Figure 1. Only those wet areas that were extensively covered with cranberry plants, *Vaccinium macrocarpon,* have been singled out and labeled as cranberry bogs. It is from these few surviving remnant cranberry bogs that we are able today to gain some information about the original wetlands in the upper portion of the Basin.

The most extensive cranberry bog, comprising some 2,000 acres, was in Cranberry Township, Crawford County, two miles south of New Washington. Before 1820, hundreds of bushels of cranberries were gathered and sold commercially for 20 to 25¢ per bushel. In 1850 cranberries brought $2.00 a bushel, but by 1855, the plants no longer grew in sufficient abundance for commercial purposes (Perrin, Battle, and Goodspeed, 1888, pp. 179, 624, 627-628; Dachnowski, 1912, p. 46). This bog is now totally drained and under cultivation in agricultural crops. Other large areas of cranberry and associated vegetation were located in the 6,000 acres of wetlands and peat deposits of Richmond Township, Huron County, and in northern Auburn Township, Crawford County. Smaller cranberry bogs occurred in Vernon, Sandusky, and doubtless other townships in Crawford County, in Crane Township north of Upper Sandusky and in Richland Township near Wharton in Wyandot County, and in Bloom Township south of Bloomville, in Eden and Clinton Townships south of Tiffin, and Scipio Township, northeast of Republic in Seneca County. Although drainage has eliminated large portions of these wetlands that once had cranberries, remnants are still extant at the three Seneca County sites, the Huron County site, and in Crane Township, Wyandot County.

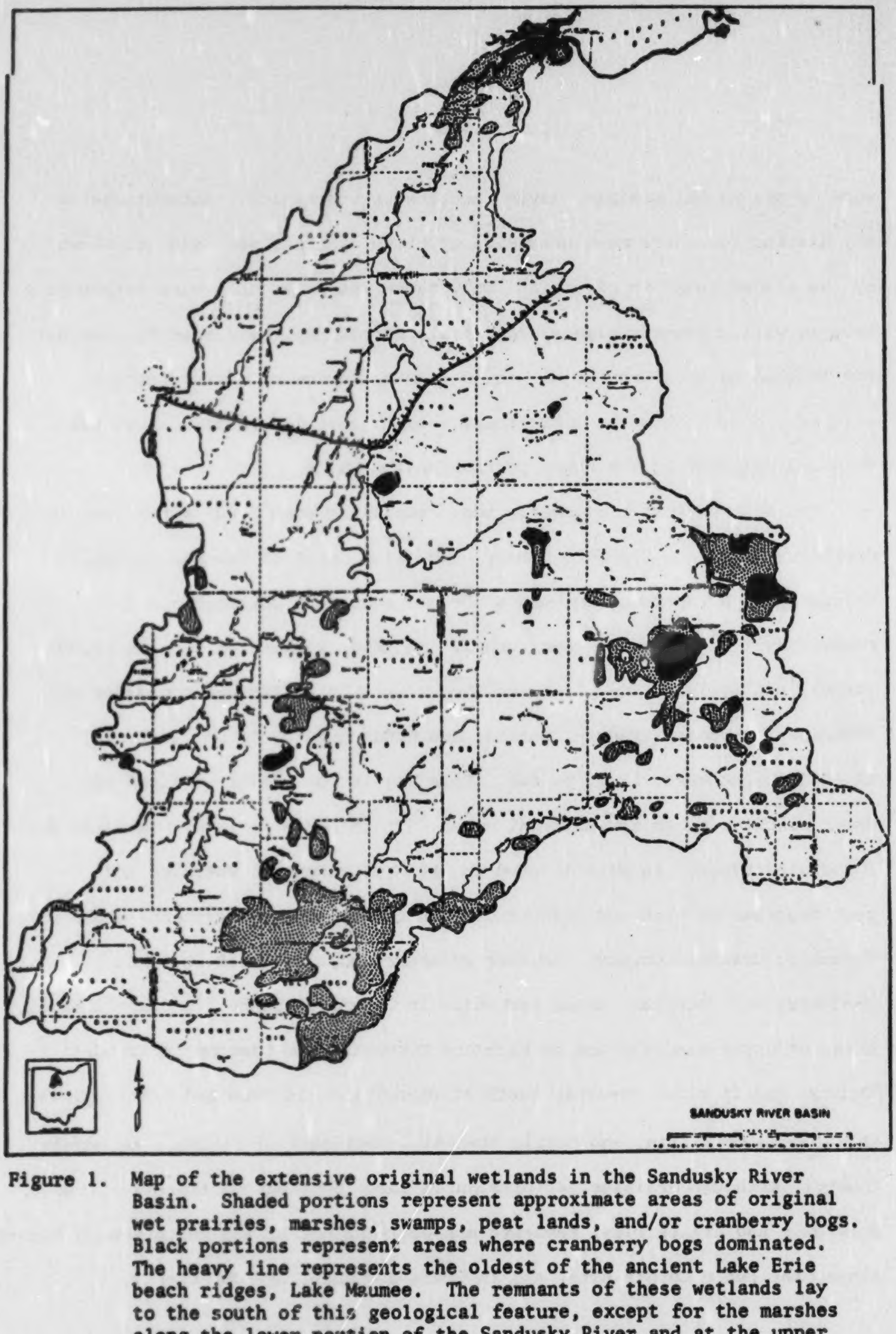

Figure 1. Map of the extensive original wetlands in the Sandusky River Basin. Shaded portions represent approximate areas of original wet prairies, marshes, swamps, peat lands, and/or cranberry bogs. Black portions represent areas where cranberry bogs dominated. The heavy line represents the oldest of the ancient Lake Erie beach ridges, Lake Maumee. The remnants of these wetlands lay to the south of this geological feature, except for the marshes along the lower portion of the Sandusky River and at the upper end of Sandusky Bay.

One of the earliest descriptions of these bogs was made by the botanist, John L. Riddell (10 July 1836, pp. 101-105).

> We had a visit this day to a Cranberry marsh, a mile and a half North West of Upper Sandusky. The marsh, a curious one, presents at a distance the appearance of a meadow. Saw no Vacciniums, no Andromedas, or other kindred shrubs. Salix myriocoides?, and Spiraea salicifolia [*S. alba*] were all the shrubs we saw on the bogs. Yet Sphagnum latifolium and a more delicate moss prevailed. I also saw abundance of Pogonia ophioglossoides, Menyanthes trifoliata, Comarum palustre [*Potentilla palustris*], and my Habenaria . . . [a new species he proposed, but never described]. The bog was a quaking one. They say here that when such a situation becomes dry, it will be consumed down to the clay, or down to the moisture, by being set on fire.

The cranberry bogs were dominated by the now extirpated cranberry plant, *Vaccinium macrocarpon,* and a number of associated plants that grew in the acid peat substrate. Sphagnum moss and sedges were the predominant contributors to the formation of the peat deposits. From the descriptions of the vegetation and lists of species that Dachnowski (1912) provided, I think that no fewer than 22 species characteristic of these acid cranberry bogs are probably extirpated from the Sandusky River Basin. These extirpated species, listed in Table 2, are today dominant and characteristic of acid bogs farther north in Wisconsin, Michigan, and Ontario. While gone from the Sanduksy River Basin, these species still survive as remnants in bogs in northeastern Ohio,,as shown by their distribution as mapped by Braun (1961, 1967). Through the years these cranberry bogs and other wetlands have been drained for agricultural purposes. Consequently, the water table has been lowered; the peat deposits and soil have dried considerably, becoming

Table 2: List of species believed extirpated from the natural remnant wetlands (former cranberry bogs) of the Sandusky River Basin based mostly on records reported in Alfred Dachnowski, (1912), and not found during field surveys by Ronald L. Stuckey.

CYPERACEAE

Carex canescens L.

Carex lacustris Willd.

Carex rostrata Stokes

Carex sterilis Willd.

Bog Sedge

Carex scoparia Schkuhr

Carex virescens L.

Cladium mariscoides (Muhl.) Torr.

Twig-rush

Dulichium arundinaceum (L.) Britt.

Three-way Sedge

Eriophorum virginicum L.

Cotton-grass

Rhynchospora alba (L.) Vahl

Beak-rush

ORCHIDACEAE

Calopogon pulchellus (Salisb.) R. Br.

Grass-pink Orchid

CORYLACEAE

Alnus rugosa (DuRoi) Spreng.

Speckled Alder

Alnus serrulata (Ait.) Willd.

Common Alder

MENYANTHACEAE

Menyanthes trifoliata L.

Buckbean

ROASCEAE

Potentilla palustris (L.) Scop.

Marsh Cinquefoil

GUTTIFERAE

Hypericum virginicum L.

Marsh St. John's Wort

ERICACEAE

Andromeda glaucophylla Link

Bog-rosemary

Pogonia ophioglossoides (L.) Ker.

Rose Pogonia

SALICACEAE

Salix pedicellaris Pursh

Bog Willow

Vaccinium corymbosum L.

High Blueberry

Vaccinium macrocarpon Ait.

American Cranberry

Ilex verticillata (L.) Gray

Winterberry, Black Alder

subjected to considerable wind erosion and repeated muck fires in the fall of the year. These modifications brought about by drainage and fire are major factors responsible for the extirpation of the sensitive northern bog species. Surviving are those species tolerant of drier, less acid soil, that persisted or invaded since the muck fires. Some distinctive surviving species of the herbaceous community are *Typha latifolia, Scirpus cyperinus, Decodon verticillatus, Polygonum sagittatum, Juncus effusus, Bidens coronata, Eupatorium perfoliatum, Asclepias incarnata,* and *Verbena hastata;* while shrubs, such as *Spiraea alba, Rosa palustris, Cephalanthus occidentalis, Sambucus canadensis, Salix* spp., and *Cornus* spp. dominate as members of the woody community.

Marshes at the Upper End of Sandusky Bay

Before settlement by European man, the vast marshes of Sandusky Bay extended upriver as far as Fort Stephenson, now Fremont. As described by Cole (1820), "The banks of the river are very low, and on each side, from its mouth, two-thirds of the way to the rapids, are extensive marshes and swamps; the face of the country is even, and the soil very rich and fertile, producing a heavy burden of grass, weeds, and plants, of great varieties." Drake (1850, p. 367) noted that "On each side of the channel there are extensive shallows, from which grasses, pond-lilies, and other aquatic plants rise into green savannas, animated with white cranes wading in the shallow water, . . ." Thorndale (1898, p. 289) described the vegetation of the Bay as being edged "with the tall, feathery plumes of the wild rice plant, intermixed with rank reeds, rushes . . . 'cat-tails,' . . . and the wild Rose of Sharon [*Hibiscus moscheutos,* swamp mallow] in full bloom, . . . Acres of wild [p. 290] rice and reeds pricked above the surface, and vast floating islands of water lilies bowed gracefully their broad leaves and creamy blossoms to the incoming swell, . . . Marine plants flourished luxuriantly under the water, and trailing masses of weed, vivid green in color, floated to the surface and frequently impeded the paddle wheels of the small tugs and steamers that ventured through the upper bay to the river beyond." Moseley (1899, p. 19) recalled the memory of individuals who said that "rushes grew over much of Sandusky Bay where now is open water." As stated by Pieters (1901, p. 66), "at the head of Sandusky Bay . . . much of the water is from 3 to 6 feet deep and supports only [p. 67] a moderate growth of *Vallisneria* and *Potamogeton* . . . The water is very muddy, and this may account for the scarcity of vegetation; for near the shore, where the water is clear, plants are more abundant. . . ." Pieters' statement about the muddy water gives us the clue to the conditions that have prevailed since the turn of the century.

Only from brief descriptive accounts like these and others can we infer the original aquatic vascular plant flora of the marshes at the mouth of the Sandusky River and the changes that it has undergone in the present century. Many of these floristic changes are described by Lowden (1967, 1969) in the flora of Winous Point at the mouth of the Sandusky River. Originally, in wet places and shallow, clear water, vast stands of grasses, such as *Zizania aquatica, Phragmites australis, Calamagrostis canadensis,* and *Spartina pectinata,* and large sedges, such as *Eleocharis smallii, Scirpus acutus, S. validus, S. Fluviatilis,* and *S. pungens* dominated. Broad-leaved cat-tail, *Typha latifolia,* was much more extensive than the then-rare narrow-leaved cat-tail, *Typha augustifolia.* Plants with large showy flowers, such as *Nelumbo lutea, Nymphaea tuberosa, Nuphar advena, Hibiscus moscheutos, Pontederia cordata,* and *Sagittaria latifolia* grew in large colonies and gave color to the marsh. In the clear open water were submersed plants, *Vallisneria americana, Potamogeton amplifolius, P. gramineus, P. robbinsii, P. zosteriformis, Ranunculus longirostris, Elodea canadensis, Najas flexilis , N. guadalupensis,* and *Myriophyllum exalbescens.*

The waters of Sandusky Bay have become quite muddy and turbid within the past century, as noted by Pieters (1901), Langlois,(1954, pp. 97-104), Lowden (1967, 1969), and doubtless other sources not cited here. These conditions have come about by: (1) runoff from the extensive erosion of the soil from the once-forested uplands of the Basin that were cleared primarily for agricultural purposes; (2) the introduction of carp (*Cyprinus carpio* L.), a species of fish that uproots and destroys aquatic plants and contributes to the overall continued turbidity by stirring up the bottom silt and keeping it in suspension; and (3) the dredging, diking, and draining of large portions of the marshland around the Bay for private, industrial, agricultural, and wildlife areas. The silted conditions and continued high turbidity levels bring about a situation, as pointed out by Langlois (1954, pp. 97-104), Lowden (1967, 1969), and Stuckey (1971), where sufficient light does not reach the submersed plants, and, consequently, submersed sensitive species of open clear waters are eliminated or drastically reduced in numbers. Examples are those submersed species mentioned above and most of those listed in Table 3. Surviving are only a few submersed, tolerant species, such as *Ceratophyllum demersum, Potamogeton pectinatus, P. foliosus, P. nodosus,* and the European invaders, *Potamogeton crispus, Najas minor,* and *Myriophyllum spicatum.* Mainly because of the physical changes in the marshes, coupled with the ever-changing water-level conditions of Lake Erie, most of the species of grasses

Table 3: List of species (usually submersed) believed extirpated from Sandusky Bay based on records reported in A. J. Pieters (1901) and not found at Winous Point as reported by Richard M. Lowden (1969).

POTAMOGETONACEAE

Potamogeton amplifolius Tuckerm.
Large-leaved Pondweed

Potamogeton gramineus L.
Grass-like Pondweed

Potamogeton robbinsii Oakes
Robbins' Pondweed

Potamogeton zosteriformis Fern
Flat-stem Pondweed

NAJADACEAE

Najas flexilis (Willd.) Rostk.& Schmidt
Naiad

Najas guadalupensis (Spreng.) Magnus
Naiad

ALISMACEAE

Sagittaria graminea Michx.

Sagittaria cuneata Sheldon
Wapato

HYDROCHARITACEAE

Elodea canadensis Michx.
Waterweed

Vallisneria americana Michx.
Wild Celery

RANUNCULACEAE

Ranunculus longirostris Godr.
White-water Crowfoot

ULTRICULARIACEAE

Utricularia gibba L.
Bladderwort

and sedges mentioned above are becoming quite rare and even the wild rice, *Zizania aquatica*, may now be extirpated. The species with large showy flowers, doubtlessly reduced in numbers from 100 years ago, undergo considerable fluctuation in size of individual populations today because of the changing water level conditions. In years of lower water, when dikes artificially maintain marshes and mudflats, *Hibiscus moscheutos* flourishes, along with several emersed species that once were rare or infrequent, such as narrow-leaved cat-tail, *Typha angustifolia*, and grasses, *Phalaris arundinacea*, *Echinochloa pungens*, *Panicum capillare*,and *P. dichotomiflorum*. On newly-created dikes, the smartweeds, *Polygonum lapathifolium* and *P. pensylvanicum*, dominate. In the marshes, Walter's millet, *Echinochloa walteri*, has been planted for wildlife food, and other European invaders, now becoming more common or abundant, are *Butomus umbellatus*, *Lythrum salicaria*, *Echinochloa crusgalli*, and *Solanum dulcamara*.

Sandusky River and Tributaries

The Sandusky River and some of its tributaries also contain many of the aquatic species that occur in the remnant original wetlands, as can be discerned from Table 1. However, submersed species are generally absent because of the turbidity of the water and the silted bottom conditions. A few southern, mudflat or shallow-water species, usually not found elsewhere in the Basin, add distinction to the river flora. Among these are *Amaranthus tuberculatus*, *Ludwigia polycarpa*, *Scirpus pungens*, *Saururus cernuus*, *Eclipta alba*, *Sicyos angulatus*, *Samolus parviflorus*, *Cyperus rivularis*, *Rumex verticillatus*, *Phystostegia virginiana*, *Lythrum dacotanum*, *Helenium autumnale*, *Phyla lanceolata*, and *Echinocystis lobata*. Most of these species occur in the lower portion of the river between Tiffin and Fremont, particularly in the shallow water areas where dolomite bedrock is exposed. The lizard's tail, *Saururus cernuus*, Figure 2, is probably the most distinctive member of this group, and its distribution, mapped in Figure 3, has been of particular interest and special study. It is known from six separate sites along the river and in isolated colonies in three tributary streams--Silver Creek, Sycamore Creek, and Wolfe Creek. In most situations, it is on the mudflats along the edge of the water or in shallow water. On the extensive, exposed dolomite north of Tiffin, it is, however, conspicuously absent. A few distinctive southern river bottom species, *Hibiscus militaris, Justicia americana, Boltonia asteroides, Strophostyles helvola, Ammannia coccinea,* and *Leucospora multifida,* are noticeably absent from the entire river. These southern species occur in the Maumee River drainage system in the adjacent basin to the west and apparently have not migrated eastward into the Sandusky River watershed. The Huron River Basin, to the east of us, shows even fewer southern river bottom species.

Man-created Ditches, Reservoirs, and Ponds

These artificially created wetlands are becoming more numerous in the Basin. The flora of these new aquatic habitats is an invading or developing type with plant propagules coming from sources within and outside the Basin. Those species that have been identified in these aquatic habitats are listed in Table 1. The species composition of these aquatic habitats and vegetational successional patterns are virtually unknown and in need of thorough studies before sound management programs can be undertaken.

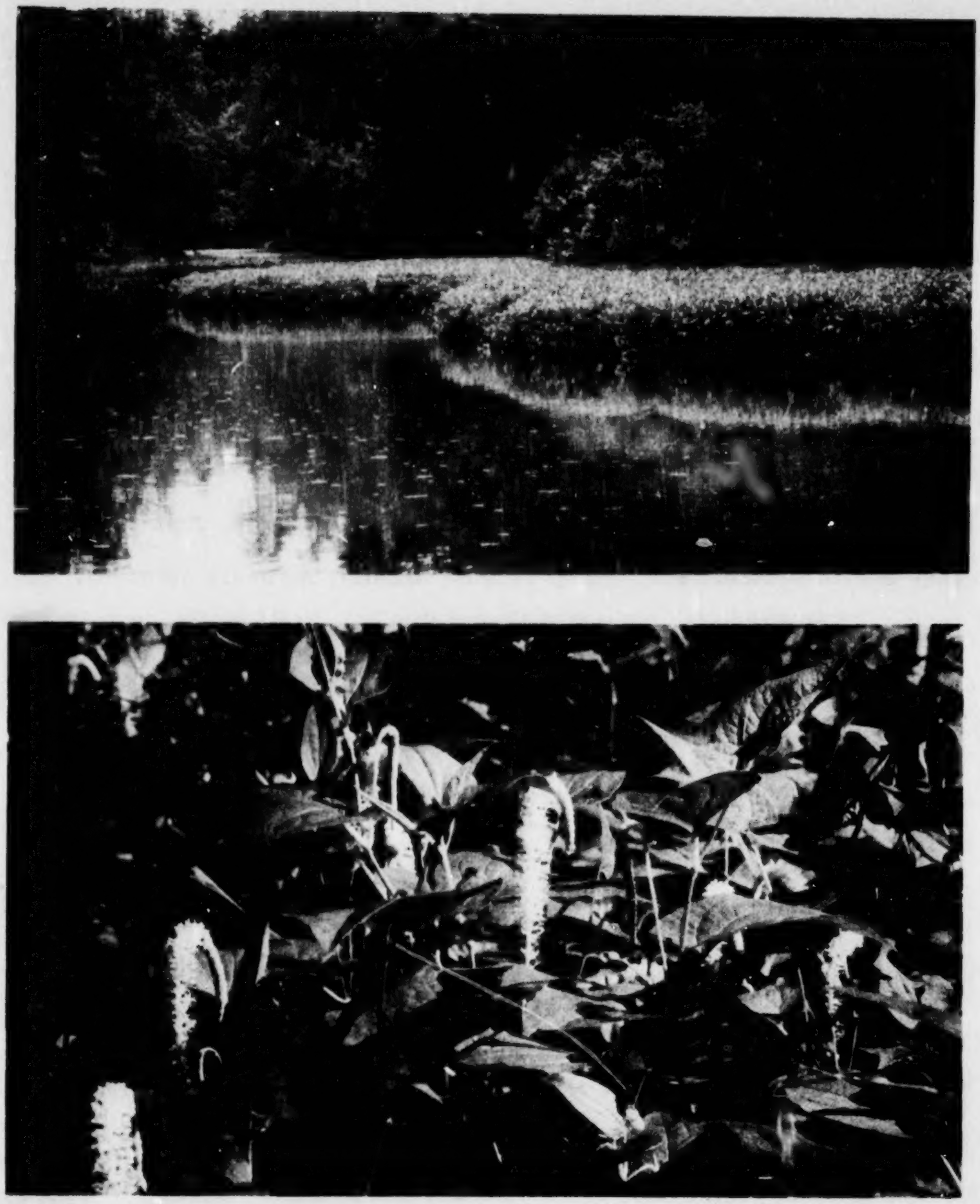

Figure 2. *Saururus cernuus*, Lizard's Tail, in the Sandusky River.
Top: View of habitat of *Saururus cernuus* in the Sandusky River, SW ¼ Section 15, Pitt Township, Wyandot County on county road 60. Photograph by Mr. John Marshall, 5 July 1975.

Bottom: View of upper portions of individual plants and inflorescences of *Saururus cernuus* in the Sandusky River, SW ¼ Section 15, Pitt Township, Wyandot County on county road 60. Photograph by Mr. John Marshall, 5 July 1975.

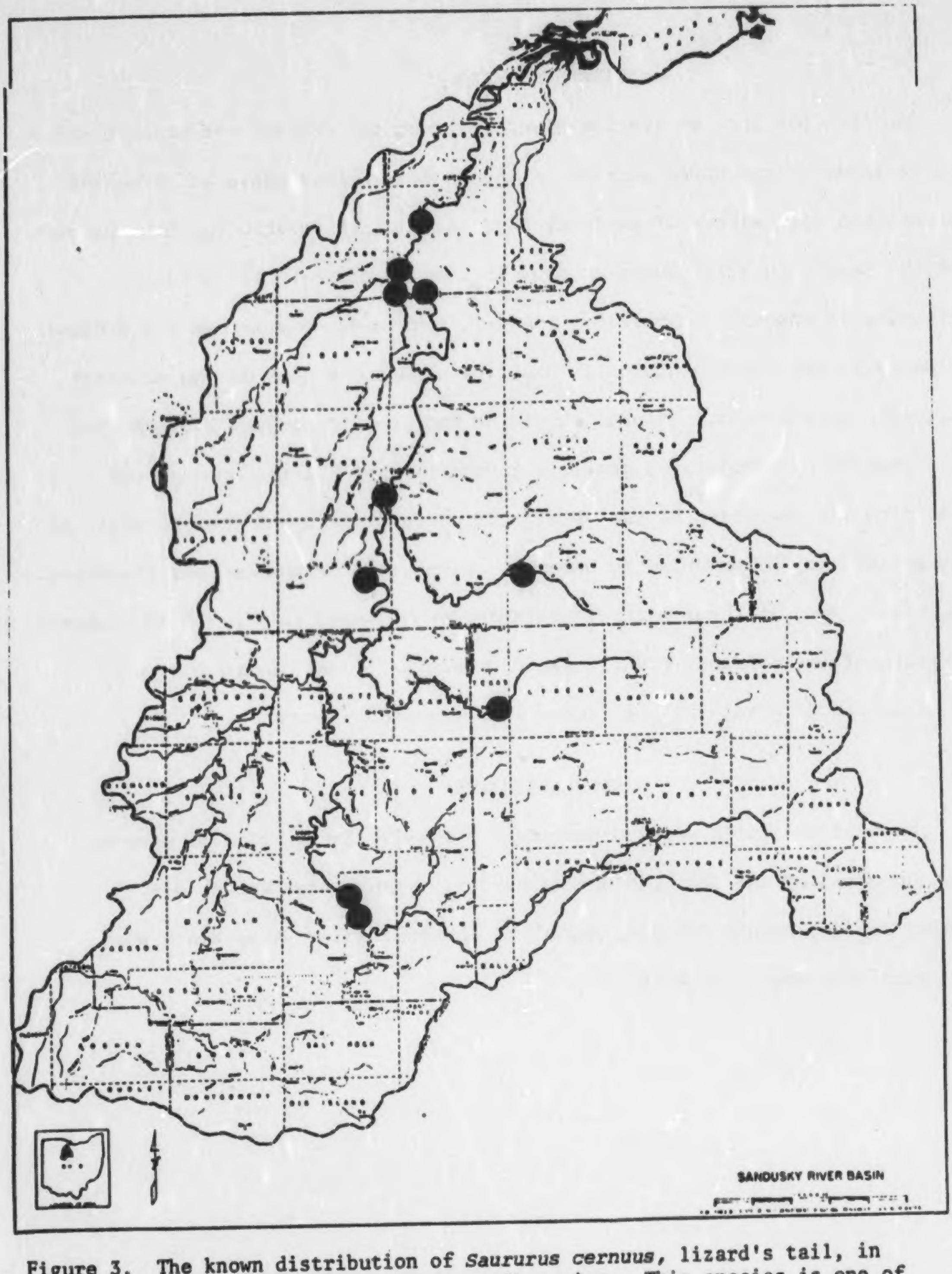

Figure 3. The known distribution of *Saururus cernuus*, lizard's tail, in the Sandusky River and its tributaries. This species is one of the most distinctive of the southern river bottom species that inhabit the Basin.

FINAL OVERVIEW

Despite the loss of species diversity from the remnant wet prairie and bog wetlands in the upper portion of the Sandusky River Basin and from the marshes and open waters of Sandusky Bay, distinctive aquatic vascular plants for the Basin are still known to grow in these habitats. The greatest diversity in species composition, however, continues to exist in the marshes of Sandusky Bay where continually changing conditions provide the greatest variation in habitats. Efforts should be made now to conduct surveys that will compile as complete as possible inventories of all the species and determine the character of the vegetation patterns left and the successional trends they may be expected to undergo. With sound management and preservation practices, many of these natural wetlands can be saved as part of the natural heritage of the Sandusky River Basin. Otherwise, total destruction of these distinctive vegetational areas will inevitably occur.

ACKNOWLEDGEMENTS

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ABSTRACT

SHORELINE CHANGES IN AND AROUND UPPER SANDUSKY BAY SINCE 1905.

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Comparison of lake charts and aerial photographs show that the shoreline of Upper Sandusky Bay has undergone major changes since 1905. The long term (1905-1973) modal recession rate along the north shore is 1-3 ft/yr and the range is from < 1 ft/yr to 7-9 ft/yr whereas the along the south shore the long term modal recession rate is 1-3 ft/yr and the range is from < 1 ft/yr to 13-15 ft/yr. Comparisons of the same shoreline stretch at different time levels show a direct relationship between lake level and recession rates. For example, along one south shore stretch in the 1957 to 1968 period the mean lake level was 570.0 ft and the recession rate was 9 ft/yr whereas in the 1968 to 1973 period the mean lake level was 571.7 ft and the recession rate was 18 ft/yr. Moreover in spite of the low relief of the shore these recession rates contribute to high recession volumes. During the period 1905-1973, about 32,000 yd^3/yr or 41,000 tons/yr of land was lost to the lake along the south shore. The principal causes for the differences in recession rates/recession volumes between the north shore and the south shore appear to be shoreline orientation and manmade structures. Winds from the northeast quadrant raise the water level at the west end of the lake and waves generated by the wind strike the north shore more directly, the drop in water level causes the waves to break farther offshore. In addition, a greater length of shoreline protected by manmade structures has reduced the recession rate along the north side.

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SHORELINE AND BATHYMETRIC CHANGES IN AND AROUND UPPER SANDUSKY BAY SINCE 1905

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INTRODUCTION

Ohio Division of Geological Survey studies of Upper Sandusky Bay show that much of the upper bay shore is receding rapidly; at the same time the upper bay is filling rapidly with sediment derived from the upper bay shore and from the Sandusky River. This report presents data on the recession rates and on the bathymetric changes that have taken place in the upper bay since 1905 in the hope that this basic scientific data will be used in the long-range land- and water-use planning of the Sandusky River basin. More specifically, we feel that attention needs to be paid to erosion of the rich agricultural land bordering the bay and to sediment pollution and infilling of the bay, which is a valuable nursery for many species of fish.

The following sentences define four of the terms used in the report:

- Recession line is the line along the shore formed by the break in slope between the upland surface and the vertical or sloping surface that fronts the lake.
- Recession rate is the average retreat of the recession line within a given time period.
- Subaerial zone is the zone above 570.0 ft (with respect to the 1955 International Great Lakes datum for Lake Erie of 568.6 ft).
- Subaqueous zone is the zone below 570.0 ft (with respect to the 1955 International Great Lakes datum for Lake Erie of 568.6 ft).

METHODS

A detailed study of the stratigraphy along Upper Sandusky Bay was done in 1973-74. In addition, echo sounder profiles of the nearshore bottom were run concurrently with the stratigraphic studies. Nearshore bottom deposits were mapped by SCUBA diving as well as by coring and grab sampling.

Two periods were selected for the recession-line map: 1905 and 1973. Preparation of the map was essentially a two-stage process: (1) preparation of an overlay map on acetate from 1973 Ohio Department of Transportation photographs at a scale of 1:4800; this overlay map shows the position of the 1973 recession line as well as roads, houses, and other prominent geographic features that can be used to insure accurate correlation and alignment of the overlapping aerial photographs; (2) projection and enlargement of the 1905 U.S. Lake Survey field sheets at a scale of 1:10,000 to the same scale as the 1973 aerial photographs and transfer of the 1905 recession line to the 1973 acetate base map. Accurate horizontal control between the 1905 field sheets and the 1973 photographs during projection and enlargement was maintained by correlation of geographic control points and lines.

Accuracy of position of the recession lines is unknown. However, there are other forms of evidence, such as ground surveys made at different periods at specific locations along the shore, that suggest that the lines are accurate to within a few tens of feet at a given location (Carter, in preparation). The greatest source of possible error appears to be human; if this is so, then errors in developing the recession lines will probably be random and deviations will tend to even out along the shoreline.

The recession rate at a given location can be determined by measuring the distance between two recession lines and dividing this distance by the time period (68 years). In measuring the recession rates along the shore we used a scale that showed the map distance for the specific recession rate classes within the time period. In this way we were able to move the scale along the breaks between the recession rate classes for later measurement of the class distance along the shore. The recession rates were divided into classes: very slow is 0-1 ft/yr; slow is 1-3 ft/yr; moderate is 3-5 ft/yr; rapid is 5-7 ft/yr; very rapid is 7-9 ft/yr; rates greater than very rapid are given in ft/yr.

The subaerial volumes were determined by multiplying the midpoint of the recession rate class--for example, very slow (0.5 ft/yr), slow (2 ft/yr), and so on--by the time period (recession length) by the distance (stretch length) along the shore which receded at that rate by the thickness of glaciolacustrine clay along the shore (fig. 1). In practice, the recession rates (and recession lengths) were fitted to a stretch length having a given thickness of clay. The subaqueous volumes were determined in a similar way through the use of recession lengths (y) and stretch lengths (x). However, the thickness of the clay for a specific rate is based on the 1973 depth (z) measured at a distance from the 1973 shoreline equal to the recession length along that stretch of shore (fig. 1). Assuming a constant slope, the subaqueous erosion has taken place within a triangular cross-section lakeward of the earliest of the two recession lines and within a triangular cross-section lakeward of the latest of the two recession lines. Superposition of the triangular sections yields a nearly rectangular section. Because subaqueous erosion below the 1973 depth (z) is not accounted for, the subaqueous volume measures are conservative.

The bathymetric changes used to determine the sedimentation rates were based on a comparison of the depths shown on the 1905 map to soundings shown on a 1962 Lake Survey map; the sounding depths are referenced to the same lake-level elevation by use of a correction factor of 0.59 ft added to the

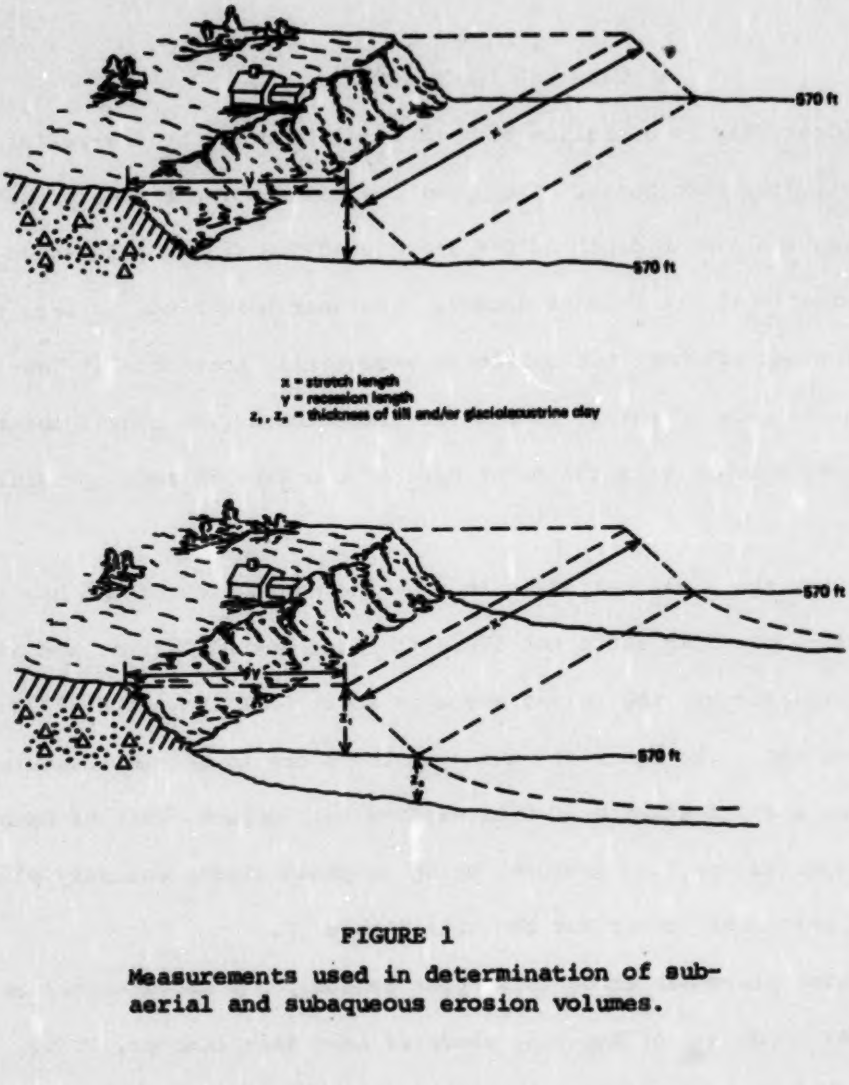
570 ft
x
y
z₁
570 ft
x = stretch length
y = recession length
z₁, z₂ = thickness of till and/or glaciolacustrine clay
570 ft
x
y
z₁
570 ft
z₂

FIGURE 1

Measurements used in determination of subaerial and subaqueous erosion volumes.

1905 depth (Rondy, 1975, written communication). A rectangular grid pattern (fig. 2) was established, and depth comparisons to the nearest 0.5 ft were made between the two maps from soundings at or near the intersections of the grid lines.

SETTING AND PROCESSES

Upper Sandusky Bay is a shallow body of water bordered by low-relief, easily erodable,clay-rich banks. The upper bay has a surface area of about 28 square miles and a mean depth of 5-6 ft below 570.0 ft (as referenced to the 1955 International Great Lakes datum). The nearshore slope is less than one degree; further offshore the bottom is essentially horizontal. The nearshore area is made up mainly of scoured glaciolacustrine clays, and the offshore bottom, which covers the major part of the Bay, is made up mainly of poorly compacted mud.

Along the bay shore the relief is low; on the south side of the bay the relief averages about 5 ft above the 570.0 ft reference elevation, and along the north side of the bay the relief averages about 6 ft above the 570.0 ft reference elevation. The material making up the shore is glaciolacustrine clay except for a short stretch of till exposed near Gypsum, west of Danbury. These shore deposits are fine grained, being composed almost entirely of clay- and silt-size particles except for the till (table 1).

Shore erosion processes erode this Upper Sandusky Bay shore nearly as rapidly as they erode any of the U.S. shore of Lake Erie (Carter, 1975, Appendix C). The most significant process is wave action, which directly scours the base of the low banks and shallow nearshore area as well as transports away the eroded material, thus keeping the shore from attaining

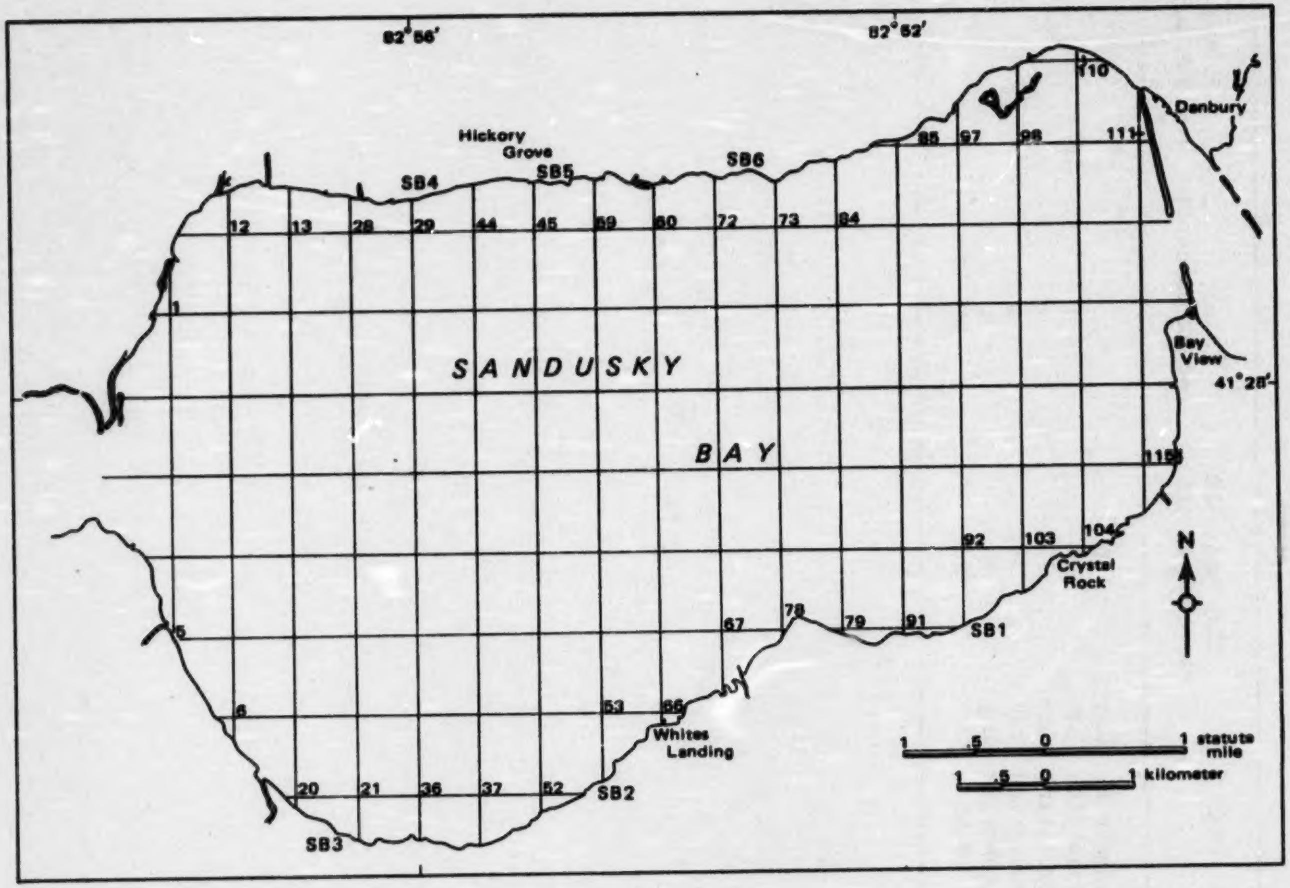
82°56'
82°52'
Hickory Grove
SB4
SB5
SB6
Danbury
110
85
97
98
111
12
13
28
29
44
45
59
60
72
73
84
1
SANDUSKY
BAY
Bay View
41°28'
115
92
103
104
Crystal Rock
N
5
67
78
79
91
SB1
6
53
66
Whites Landing
1 .5 0 1 statute mile
1 .5 0 1 kilometer
20
21
36
37
52
SB2
SB3

FIGURE 2

Upper Sandusky Bay sample locations and bathymetric grid.

Table 1: Size analyses of upper Sandusky Bay shore deposits

Location	Material	Clay and silt (weight percent)	Sand (weight percent)	Gravel (weight percent)
SB 1	Glaciolacustrine clay	100		
SB 2	Glaciolacustrine clay	99	1	
SB 3	Glaciolacustrine clay	96	4	
SB 4	Glaciolacustrine clay	99	1	
SB 5	Glaciolacustrine clay	99	1	
SB 6	Till	82	14	4

a more stable configuration. Because of the shallow depth and relatively short fetch (maximum 6 miles) the largest waves generated by storm winds on the upper bay are about 3 ft high. Mass-wasting processes such as rotational slumps and debris flows do take place along the shore, but these processes are related mainly to wave scour, which undercuts the bank face or keeps it at a steep angle to the horizontal. However, processes such as slaking and frost action decrease the strength of the shore deposits, making the shore recede that much more rapidly when subjected to wave attack.

RECESSION RATES

Both the north shore and the south shore of the upper bay had the same modal recession rate of 1-3 ft/yr from 1905 to 1973, but the south shore showed a much greater range in recession rates than the north shore within the same period: less than 1 ft/yr to 13-15 ft/yr versus less than 1 ft/yr to 7-9 ft/yr (table 2). Moreover, 62 percent of the south shore receded at 3-5 ft/yr or more; whereas only 9 percent of the north shore receded at 3-5 ft/yr or more. This difference is even more significant because the strongest and most persistent winds come from the southwest quadrant (table 3). Manmade structures are an obvious reason for some of the difference: 10 percent of the length of the north shore is protected and less than 1 percent of the length of the south shore is protected. However, we think that the principal reason for the overall difference in recession rates is shoreline orientation. When the wind blows from the west across the upper bay as well as across and down the long axis of the lake, the wind stress causes the water level to drop in the upper bay as well as in the western part of the lake. Because of the decrease in water depth the waves break further offshore along the north shore of the upper bay, thereby expending most of their energy away from the clay banks. On the other hand, when the wind blows from the northeast quadrant

Table 2: Recession rates and sum of the individual shoreline lengths for upper Sandusky Bay, 1905 - 1973

Recession rate (ft/yr)	Shoreline lengths (ft)	
	North shore	South shore
<1	18,150	3,300
1-3	18,350	18,150
3-5	2,950	12,050
5-7	900	12,800
7-9	150	5,350
9-11		2,800
11-13		1,400
13-15		800
Protected	4,500	150

Table 3: Wind data for Sandusky, Ohio, for the period 1928 through 1937*

Direction	Prevailing wind (percent of ice-free period)		
	0-12 mph	13-24 mph	25 mph and over
N	8	<1	
NE	12	1	
E	12	1	
SE	6	<1	
S	15	1	
SW	19	6	<1
W	9	3	<1
NW	6	2	<1

* U. S. Army Corps Engineers, 1953, pl. 1.

across the upper bay as well as across and down the long axis of the lake, the wind stress causes a rise in the water level in the upper bay as well as in the western part of the lake; as a result the waves break closer to the south shore of the upper bay, thereby expending most of their energy directly into the clay banks. This hypothesis seems likely,especially because of the similarity in the shore deposits and offshore profiles along the two sides of the upper bay; these two variables play an important role in recession rates elsewhere along the Ohio shore of Lake Erie (Ohio Division of Geological Survey, in preparation). An example of water-level variations during two winds from different directions is shown in Table 4. Moreover, the importance of lake level to shore erosion can be illustrated by comparing the recession rates during two periods in which there was a pronounced difference in lake level. For example, along one south shore upper bay stretch in the 1957 to 1968 period the mean lake level was 570.0 ft and the recession rate was 9 ft/yr; whereas in the 1968 to 1973 period along the same stretch the mean lake level was 571.7 ft and the recession rate was 18 ft/yr (Ohio Division of Geological Survey, unpublished map).

RECESSION VOLUMES

The recession volumes parallel the recession rates because of the similar relief and offshore slopes along the upper bay shore. Therefore, because of the much higher recession rates and slightly greater length, the south shore contributes nearly four times the amount of sediment to the upper bay as the north shore (table 5). The total sediment load from both subaerial and subaqueous recession for the upper bay is about 131,000 yd^3yr or about 209,000 tons/yr (table 5).

Table 4: Water-level changes with wind speed and direction, lower Sandusky Bay gage station

Time (hrs)	Northeast wind*			Northwest wind**		
	Direction	Speed (knots)	Lake level (ftabove IGLD)	Direction	Speed (knots)	Lake level (ft above IGLD)
0200	NE	25	4.2	NE	23	5.6
0400	ENE	20	4.6	NNW	16	5.0
0600	NE	25	5.4	NW	32	4.7
0800	ENE	25	5.7	NW	39	4.3
1000	NE	20	5.9	NW	40	3.7
1200	NE	27	6.1	NW	37	3.5
1400	NE	35	6.1	NW	36	3.1

*14 March 1975 (U.S. Coast Guard Station, Marblehead).
** 3 April 1975 (Norfolk and Western coal dock, Sandusky).

Table 5: Recession volumes and recession weights for upper Sandusky Bay 1905 to 1973

	North Shore	South Shore	Totals
Subaerial volume (yd^3/yr)	12,792	51,447	64,239
Subaqueous volume (yd^3/yr)	13,517	53,032	66,549
Weight (tons/yr)*	42,094	167,166	209,260

* Based on a density of 1.9 g/cc.

SEDIMENTATION RATE

The generalized depositional area that was determined from water-depth comparisons in 1905 and in 1962 has an area of about 21.9 square miles (fig. 3). Within this area water-depth comparisons were made at 90 locations, giving a location density of about 4 locations/square mile. Of the 90 locations, 88 showed a decrease in water depth and two showed no change in water depth (table 6). The 88 decreases in water depth ranged from 0.5 ft to 2.0 ft. The mean change in depth of the 88 points is 1.0 ft; therefore, within the 57-year period from 1905 to 1962, the average sedimentation rate based on U.S. Lake Survey water-depth measurements was 0.018 ft/yr (5.5 mm/yr).

SEDIMENT BUDGET

The two principal sources of sediment to the upper bay are: the shore and the Sandusky River (fig. 4). U.S. Geological Survey measurements of the suspended sediment load for the river show a load of about 284,000 tons/yr for the period 1946-1970 (Anttila, 1975, oral communication), whereas, as previously mentioned, the load from the shore is about 209,000 tons/yr. Translating the weight of the total stream and shore load (493,000 tons/yr) into a volume, by using a density of 1.9 g/cc, gives 308,000 yd^3/yr. At this volume the bay bottom in the generalized depositional area of 21.9 square miles is covered by sediment to a depth of 0.014 ft/yr (4.3 mm/yr). This value is about 1 mm/yr less than the sedimentation rate calculated by comparing changes in water depth in 1905 and in 1962. There are several possible reasons for this difference. Among them are: the "average" sedimentation rate for the 1905 to 1962 interval, the water-depth measurements (and the determination of the mud-water interface), and sediment compaction. For example, the sedimentation rate determined for the 1905 to 1962 interval does not reflect

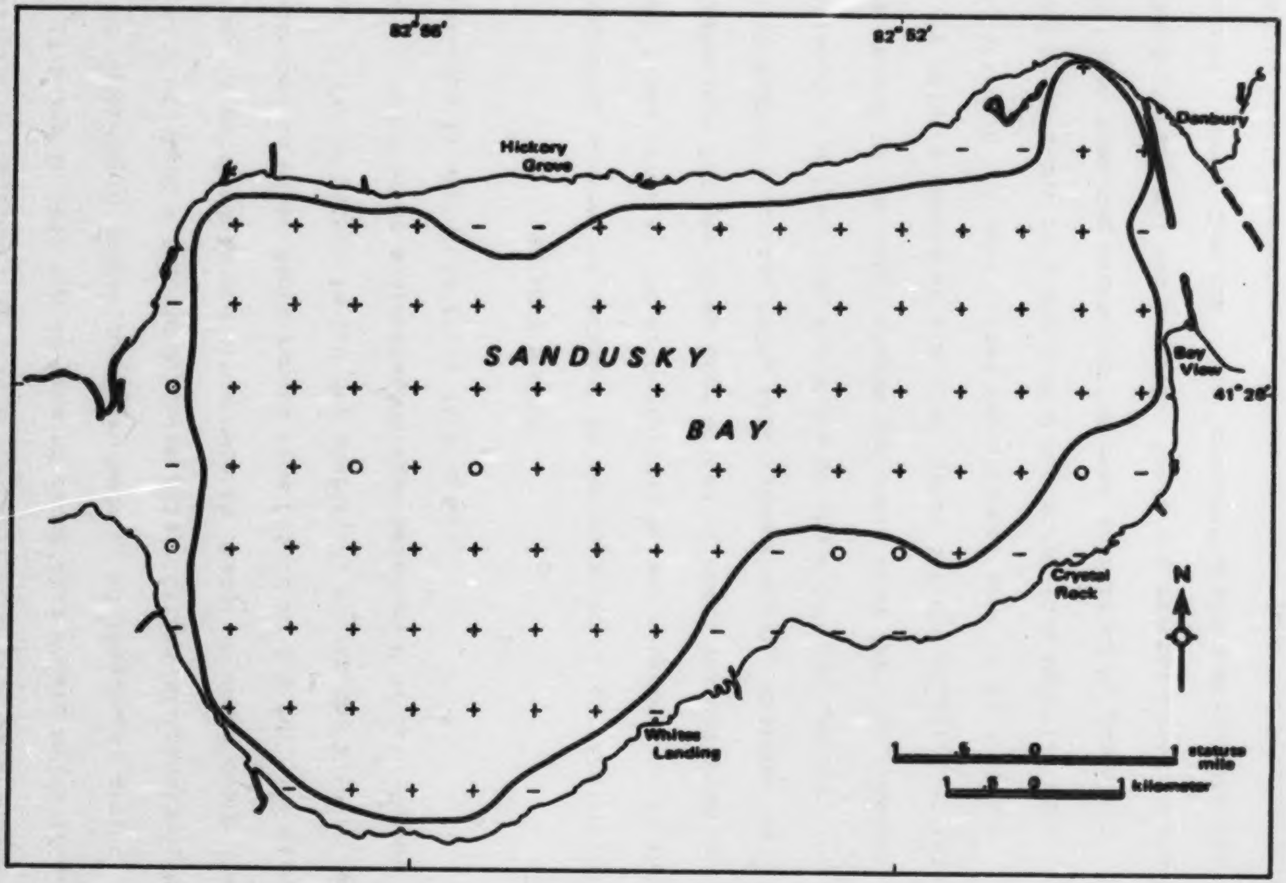
82°56'
82°52'
41°28'
Hickory Grove
Danbury
Bay View
Crystal Rock
Whites Landing
SANDUSKY BAY
N
1 .5 0 1 statute mile
1 .5 0 1 kilometer

FIGURE 3

Bathymetric changes between 1905 and 1962 and generalized depositional area.

Table 6: 1905 and 1962 soundings and differences in water depth

Location point	1905 depth (ft)	1962 depth (ft)	1905-1962 difference (ft) **
1*			
2	3.0	3.0	0.0
3	2.0	3.0	-1.0
4	2.0	2.0	0.0
5*			
6	1.5	1.0	0.5
7	4.5	3.0	1.5
8	3.5	3.0	0.5
9	3.5	3.0	0.5
10	2.5	2.0	0.5
11	4.0	3.5	0.5
12	3.5	3.0	0.5
13	5.5	4.0	1.5
14	5.5	4.0	1.5
15	4.5	4.0	0.5
16	4.5	4.0	0.5
17	4.5	4.0	0.5
18	4.5	4.0	0.5
19	4.5	3.0	1.5
20*			
21	3.5	3.0	0.5
22	5.0	4.0	1.0
23	5.5	4.5	1.0
24	6.5	4.5	2.0
25	5.0	5.0	0.0
26	5.5	5.0	0.5
27	6.0	5.0	1.0
28	4.5	4.0	0.5
29	4.5	4.0	0.5
30	6.5	5.0	1.5
31	6.5	5.0	1.5
32	6.0	5.0	1.0
33	6.0	5.0	1.0
34	5.5	5.0	0.5
35	5.5	4.0	1.5

Table 6: 1905 and 1962 soundings and differences in water depth (continued)

Location point	1905 depth (ft)	1962 depth (ft)	1905-1962 difference (ft) **
36	3.5	3.0	0.5
37	3.5	3.0	0.5
38	5.0	4.0	1.0
39	6.0	5.0	1.0
40	6.5	5.0	1.5
41	5.0	5.0	0.0
42	6.5	5.0	1.5
43	6.0	5.0	1.0
44	3.5	4.5	-1.0
45	4.5	5.0	-0.5
46	6.0	5.0	1.0
47	6.0	5.0	1.0
48	5.5	5.0	0.5
49	6.5	5.0	1.5
50	5.5	5.0	0.5
51	5.0	4.0	1.0
52*			
53	4.5	4.0	0.5
54	5.5	5.0	0.5
55	6.0	5.0	1.0
56	6.0	5.0	1.0
57	6.5	5.0	1.5
58	6.5	5.0	1.5
59	5.5	5.0	0.5
60	5.5	4.0	1.5
61	6.5	5.0	1.5
62	6.5	5.0	1.5
63	6.5	5.0	1.5
64	6.0	5.0	1.0
65	5.5	4.5	1.0
66*			
67	2.5	4.0	-1.5
68	6.0	5.0	1.0
69	6.0	5.0	1.0
70	6.5	5.0	1.5

Table 6: 1905 and 1962 soundings and differences in water depth (continued)

Location point	1905 depth (ft)	1962 depth (ft)	1905-1962 difference (ft) **
71	6.5	5.0	1.5
72	5.5	5.0	0.5
73	5.5	5.0	0.5
74	6.5	5.0	1.5
75	6.5	5.0	1.5
76	6.0	5.0	1.0
77	4.5	5.0	-0.5
78*			
79*			
80	5.0	5.0	0.0
81	6.0	5.0	1.0
82	6.5	5.0	1.5
83	6.5	5.0	1.5
84	6.0	5.0	1.0
85*			
86	6.5	5.0	1.5
87	6.5	5.0	1.5
88	6.5	5.0	1.5
89	6.0	5.0	1.0
90	5.0	5.0	0.0
91*			
92	4.5	4.0	0.5
93	5.5	5.0	0.5
94	6.0	5.0	1.0
95	6.5	5.0	1.5
96	6.5	5.0	1.5
97	3.5	4.0	-0.5
98	4.5	5.0	-0.5
99	6.5	5.0	1.5
100	6.0	5.0	1.0
101	5.5	5.0	0.5
102	5.5	5.0	0.5
103	1.5	3.5	-2.0
104*			
105	5.0	5.0	0.0

Table 6: 1905 and 1962 soundings and differences in water depth (continued)

Location point	1905 depth (ft)	1962 depth (ft)	1905-1962 difference (ft) **
106	5.0	4.5	0.5
107	6.0	5.0	1.0
108	7.0	6.0	1.0
109	5.5	4.0	1.5
110	2.5	2.0	0.5
111	5.5	4.5	1.0
112	7.5	8.5	-1.0
113	5.5	5.0	0.5
114	4.5	4.0	0.5
115	2.5	3.0	-0.5

*No 1905 soundings near these points; symbols indicating erosion or deposition for these points (fig. 3) are inferred from adjacent points.

**To nearest 0.5 ft.

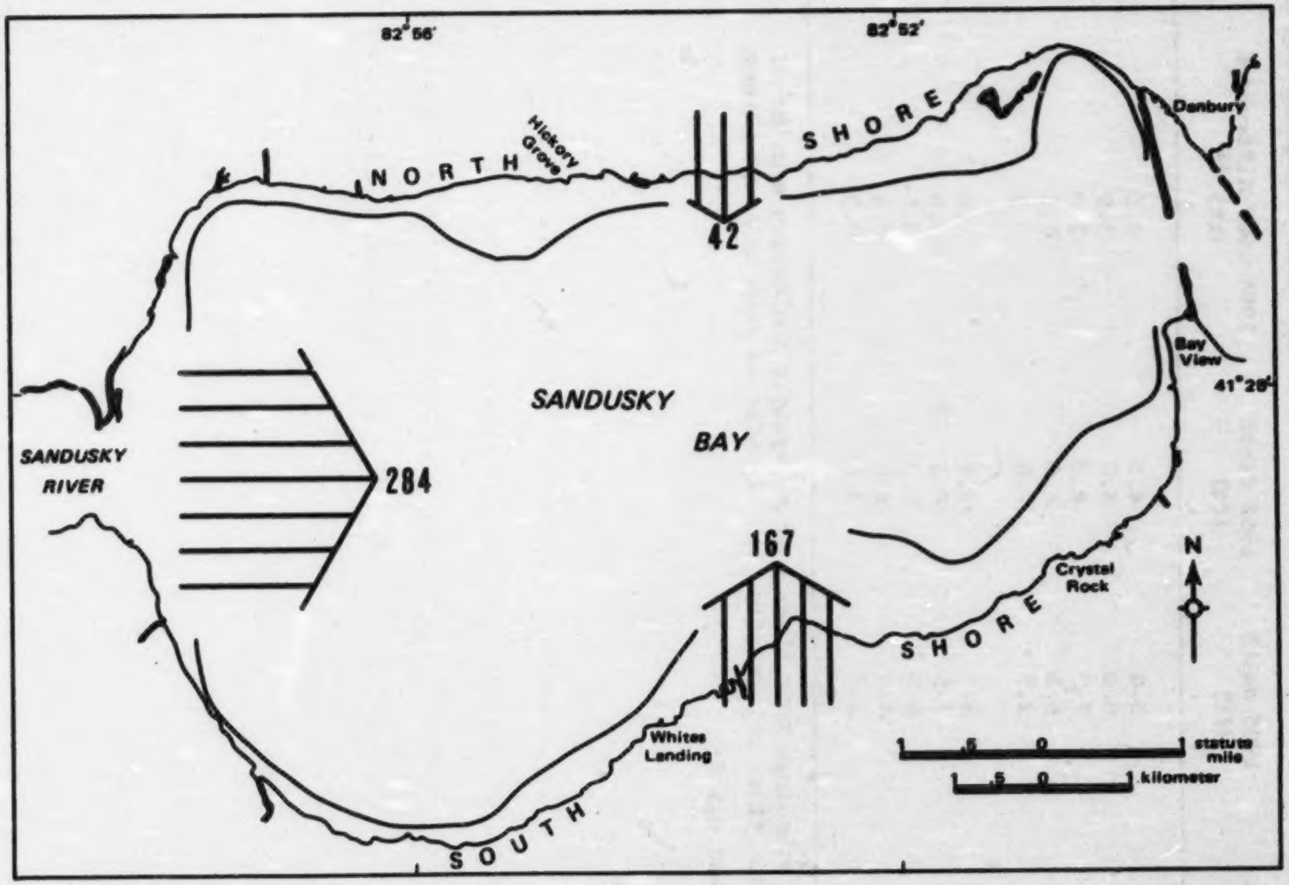
82°56'
82°52'
41°28'
NORTH SHORE
Hickory Grove
Danbury
Bay View
42
SANDUSKY BAY
SANDUSKY RIVER
284
167
SOUTH SHORE
Whites Landing
Crystal Rock
N
1 .5 0 1 statute mile
1 .5 0 1 kilometer

FIGURE 4

Principal sources of fine-grained sediment
to upper Sandusky Bay (thousands of tons/yr.)

sedimentation intensity within a shorter time interval; the sediment load for the Sandusky River has almost certainly increased greatly in the past 30 years because of changes in land use; one of the principal changes is the cultivation of fields for soybeans in areas formerly left as meadowland (Steiger, 1975, oral communication). The greater sedimentation rates determined since the early 1940's (Walters and Herdendorf, this volume) probably reflect this change. Comparison of the 1905 water depths to the 1962 water depths is probably imprecise because of the way the surveys were made; the 1905 depths were probably determined with graduated poles, whereas the 1962 depths were determined with an echo sounder (Monteith, 1975, oral communication). Lastly, the volume used in the theoretical rate of 0.014 ft/yr is based on a compact sediment with a density of 1.9 g/cc; this value is too high for the sediment that now covers the central part of the upper bay bottom; for this reason, excluding,of course,sediment loss from the bay, the theoretical rate is too low. However, if the average sedimentation rate for the upper bay of about 10 mm/yr since the early 1940's (Walters, 1975, oral communication) is representative of the upper bay, then it seems probable that most of the stream and shore load is now settling out in the upper bay.

CONCLUSIONS AND FURTHER THOUGHTS

Upper Sandusky Bay receives about 209,000 tons/yr of sediment from erosion of the upper bay shore and about 284,000 tons/yr of sediment from the Sandusky River. Most of this sediment appears to be deposited in the upper bay, where sedimentation rates of 5.5 mm/yr or slightly greater seem likely. Therefore, if the quantity of sediment derived from the shore and the river does not change and the sedimentation rate stays constant, the upper bay has a life expectancy of 300 to 400 years. Concurrent with the loss of land from the upland area and the shore,and deposition of the sediment in the bay will be an increase in turbidity and more of a change in the texture (s) of the bay bottom as well as an increase in the eutrophic state of the bay. However, the loss of bay shore land and rate of bay sedimentation need not be nearly so great; shore protection in the already partially sheltered bay is used in some places to prevent or greatly reduce shore erosion. Lake regulation to reduce the maximum levels of Lake Erie and the upper bay would also reduce the rate of bay shore erosion (recession) and bay sedimentation. Lastly, the Sandusky River basin, including the bay, cannot be used as a model for the lake in terms of sediment load. About 60 percent of the sediment coming into the upper bay is from the Sandusky River, and about 40 percent is from the bay shore. Within the Lake Erie drainage basin, about 75 percent of the sediment coming into the lake is from the shore, and about 25 percent is from the tributary streams (Carter, 1975, p. 2).

ACKNOWLEDGMENTS

D. R. Rondy, of the U.S. Lake Survey Center, calculated the water-level factor to be used so that the 1905 soundings could be compared to the 1962 soundings; William Kennedy of the U.S. Weather Service furnished us with wind data from the Norfolk and Western anemometer in Sandusky, and P. W. Anttila of the U. S. Geological Survey furnished us with sediment load data for the Sandusky River. We also wish to thank H. R. Collins, State Geologist, for permission to publish this paper, and J. S. Brown for technical assistance.

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ABSTRACT

PHYTOPLANKTON POPULATIONS OF SANDUSKY BAY

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The net phytoplankton of Sandusky Bay, Lake Erie was sampled monthly during 1974. Dominant phytoplankters were diatoms and blue-green algae, dinoflagellates and cryptomonads being of relatively little significance. Populations remained at low levels during the winter months with the diatom *Stephanodiscus binderanus* dominant. An unusual bloom of 200,000 filaments/l of the brackish-water centric diatom, *Skiletonema subsalsum*, occurred in April. This small, filamentous diatom, never having been previously reported from the Western hemisphere, reached levels of greater than 3.7×10^8 fil/l in April 1973. The origin of this European diatom and reason for its great abundance are entirely unknown. Blue-green algae, primarily *Aphanizomenon flos-aquae*, increase in abundance during the summer, reaching bloom proportions in July at greater than 3×10^6 fil/l. Levels of *A. flos-aquae* during 1974 were considerably lower than encountered in 1973 when blooms of 10^8 fil/l were observed. Total numbers of phytoplankton declined to less than 50,000/l during the fall, with communities composed primarily of species of the diatom *Melosira*.

Distribution of phytoplankton in Sandusky Bay was irregular, possibly dependent upon variations in nutrient levels, wind action, turbidity, and the grazing of large numbers of herbivorous zooplankton and fishes. General distribution patterns showed the highest abundance along the windward shore and closest to open water. Phytoplankton species encountered were those commonly associated with eutrophic conditions, giving testimony to the eutrophic, nutrient-laden waters of Sandusky Bay.

ABSTRACT

BENTHIC MACROINVERTEBRATE POPULATIONS OF SANDUSKY BAY

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The aquatic ecology of western Sandusky Bay is extensively influenced by the shallowness, turbidity, and unconsolidated sediments of the Bay. Water quality, bottom sediments and species composition of the bay are changing as a result of land use patterns. Benthic species diversity is low. The dominant taxa found in a 2-year study were three genera of oligochaetes (sludge worms) and three genera of chironomids (midge) larvae. March 1973 was the month of peak abundance (4485 organisms/m^2). The highest populations occurred at the mid-bay stations and the lowest density were found near the shore. In the past 35 years oligochaetes have replaced dipterans as the most numerous benthic macroinvertebrates in Sandusky Bay.

BENTHIC MACROINVERTEBRATE POPULATIONS OF SANDUSKY BAY

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Columbus, Ohio

INTRODUCTION

The project, of which this study was a part, was designed and conducted to attain an overview of the ecological components and processes occurring in Sandusky Bay and several associated tributaries. This work was undertaken to determine the environmental suitability of a tract of land bordering western Sandusky Bay for construction and operation of an electric generating station. The objective of this particular study was to determine the species composition, population density, and seasonal variations of the benthic macroinvertebrate fauna of Sandusky Bay.

HABITAT BASE

Sandusky Bay is approximately four times as long as wide with an average depth of 1.6 meters. The Bay has 72 kilometers of shoreline surrounding an area of water approximately 162 square kilometers. Some morphometric parameters, such as depth and shoreline slope, are subject to rather rapid change due to wave erosion and water level fluctuations of Lake Erie.

Decreased velocity of tributaries as they enter Sandusky Bay caused the settling of suspended material. The soils of the drainage area of the Sandusky River and Bay are classified as dark colored, poorly drained, clay soils. The average annual sediment load carried by the Sandusky River is over 400,000 tons. The composition of this sediment is approximately 61% clay, 37% silt, and 2% sand (Youngquest, 1953). In view of the shallowness of the

Bay, the large surface area and high sediment load from the Sandusky River, wind action is instrumental in perpetuating a highly turbid water. The bay is predominantly a brown muddy hue. Extensive erosion of the south shore and to a lesser extent the north shore also contributes to the suspended sediment. The surface sediment of the bay is predominantly silt with two sand spits at the outlet. Most of the clay is held in suspension and passes out of the bay for deposition in the central and eastern basins of Lake Erie.

The land around Sandusky Bay is monotonously flat and swampy. The small streams and marshes that originate only a few miles inland are controlled almost exclusively by the fluctuations of the bay itself. The larger streams are also controlled by the bay for several miles inland. The effect is that of an estuary.

The surrounding wetlands began to be drained for agriculture around 1870 (Langlois, 1954). From descriptions of the shore area then and now, the only parts that seem to have remained relatively unchanged are the shore marshes. The bay itself has undergone considerable changes in the last 150 years. Shaffer (1951) indicated that the south shoreline was about 350 meters farther north than in 1820. He concluded that the area of least shore loss was the eastern bay with an average loss of 1.5 meters per year. The greatest shore loss was 2.8 meters per year on the south shore of the western bay. If the same rate has continued, the shoreline is 57 meters farther south today than it was in 1951.

METHODS

During the two-year period, November 1972 thru October 1974, a total of 43 stations was sampled in Sandusky Bay and adjacent waters to determine the spatial distribution of the benthic fauna (fig. 1). The sampling area, for

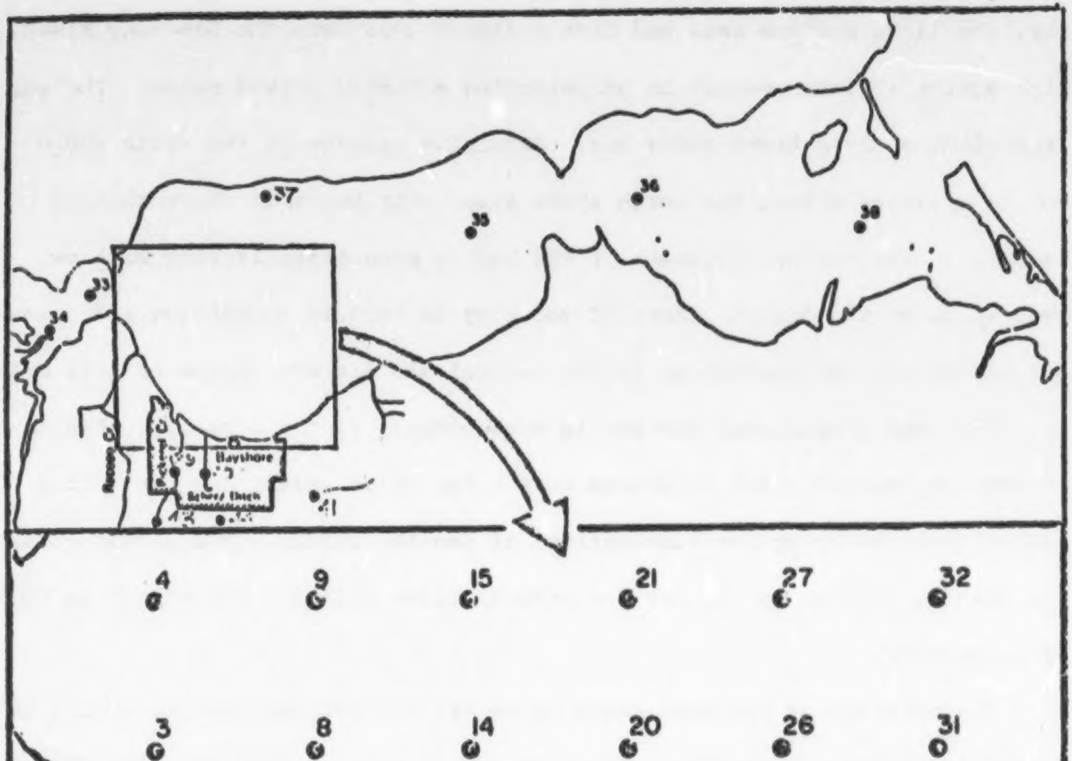
37
36
35
38
33
34
Racoon Cr.
Pickerel Cr.
Bayshore
Scherz Ditch
41
4
9
15
21
27
32
3
8
14
20
26
31
2
7
13
19
25
30
1
6
12
18
24
29
5
11
17
23
28
22
10
16
Racoon Cr.
Pickerel Cr.
Bayshore
Scherz Ditch

Figure 1. Sandusky Bay Sampling Stations. Hatched line encloses proposed plant site.

the most part, was confined to the western end of Sandusky Bay. North of the proposed plant site, 32 sampling stations (nos. 1 thru 32 inclusive) were established in the bay. These sampling stations were laid out on a one-square kilometer grid. The base lines for this grid were Latitude 41°25' and Longitude 82°58'. From this base the grid extended for 5 kilometers north and 5 kilometers east.

A series of sampling stations was also established along the main channel of the bay. The first station (No. 34) was at the mouth of Sandusky River at the swampy peninsula, known as Dutch Gap. The second station (No. 33) was between Canvasback Point and Graveyard Island in Muddy Creek Bay. Two additional stations (nos. 35 and 36) were on either side of the bay bridges. The last bay station (No. 38) was between the city of Sandusky and Johnson Island. For comparison, a station (No. 37) was placed on the north shore of the western end of the bay. Additional stations were established in both Pickerel Creek and the Schertz Ditch. Both of these streams had benthos sample stations at U.S. Route 6 (nos. 39 and 40) and also 2 kilometers farther south (nos. 43 and 44). A final station was located at the outlet of Miller Blue Hole (No. 41) southeast of the site.

The first and preliminary sampling was carried out during November 1972. A saturation sampling was based on a one kilometer grid of the southern shore of the western basin and a transect of stations from the Sandusky River mouth to the outlet of the bay. Analysis of these samples indicated that such sampling intensity was not needed. The number of sample sites was later reduced by two-thirds but included the addition of six sampling stations, one station along the north shore of the western basin and five tributary locations.

The sampling sites were selected to obtain information from potentially three different habitats: (1) the open bay, (2) the shore and near-shore area of the bay adjacent to the proposed construction site, and (3) the tributaries in the vicinity of the same site.

Most bottom samples in the bay were taken from a small motor-boat with a 9 X 9-inch Ekman dredge (some November 1972 samples were taken with a 6 X 6-inch Ekman dredge and a Ponar dredge). The stream samples, except Miller Blue Hole, were also taken with the same Ekman dredge sampler. The Miller Blue Hole was sampled using a Surber sampler. On station, each Ekman sample was washed through a No. 40 sieve (0.42 mm). The material that remained on the screen was then reversed-washed into a sample container and preserved with 10% formalin.

In the laboratory, each sample was again washed through a No. 50 sieve (0.30 mm). The purpose of this wash was to remove the organisms and debris from the formalin. The sieve contents were placed (in small increments) into a white enamel pan. All visible organisms were removed by hand with the aid of a 4X magnifier. The organisms so picked were then transferred to 80% ethanol.

The two groups of organisms requiring special preparation were chironomid larvae and oligochaetes. Each group required a different method as outlined below. The chironomid larvae and oligochaetes were separated from each other and other organisms at 10X magnification using a dissecting microscope. The preparation of chironomids and oligochaetes was as follows:

Chironomid larvae:

1. All larvae from a given collection were placed in a numbered container of super-saturated potassium hydroxide solution. The larvae remained in this solution for 48 hours.

2. The cleared larvae were then removed from the KOH, and washed with several changes of water.

3. The washed larvae were then transferred to a shallow culture dish with water. A needle-point forcep and a dissecting microscope were used to remove the head from each larva. Each head was then transferred to a microscope slide with Hoyer's solution of sufficient volume to fill out the area under a 22 mm square coverslip. Each slide could accomodate 12 chironomid larvae heads.

4. The slide was then placed on the stage of a dissecting scope. With a micro-point probe each head was adjusted to lie ventral surface up. A coverslip was then placed on top. This caused the Hoyer's solution to flow slightly in adjustment to the weight of the coverslip. Almost invariably, some of the heads rolled over. A long, very thin copper wire inserted under the coverslip was used to reposition the heads that had shifted to an improper position. Proper identification could not be accomplished unless the head was in the ventral side-up position. The slides were then put aside for about 24 hours.

5. Identification required a compound microscope. The magnification requirements varied from 100X to 660X.

Oligochaetes:

1. Each worm was placed on a separate microscope slide, with several drops of a lactophenol solution called Amen's solution.

2. As necessary, each worm was straightened. A coverslip was then added. If needed, additional Amen's solution was introduced under the coverslip.

3. Each slide was then set aside for at least 48 hours. Amen's solution will not set up, so care was necessary to keep the slight upright at all times.

4. Identification was accomplished using a high power microscope. The magnification range was 100X to 660X.

RESULTS

The benthic community of Sandusky Bay and tributaries is primarily composed of oligochaete worms and chironomid (midge) largae. The fauna was dominated by six species, three oligochaetes *(Branchiura sowerbyi, Limnodrelus hoffmeisteri,* and *Peloscolex ferox)* and three dipterans *(Chironomus c. plumosus, Procladius bellus,* and *Coelotanypus scapularis)*. Together these

Table 1: Benthic macroinvertabrates collected from Sandusky Bay and adjacent waters November 1972 to October 1974

Phylum Ectoprocta (Bryozoa)	*Plumatella emarginata*
Phylum Annelida	
Class Oligochaeta	
Order Plesiopora	
Family Tubificidae	
	Branchiura sowerbyi
	Limnodrilus hoffmeisteri
	Peloscolex ferox
	Amphichaeta sp.
	Bothrioneurum vejdovskyanum
Class Hirudinea	
Order Rhynchobdellidae	
Family Glossiphoniidae	
	Helobdella stagnalis
	Glossiphonia complanata
Phylum Arthropoda	
Class Insecta	
Order Diptera	
Family Culicidae	
	Chaoborus sp.
Family Ceratopogonidae	
	Palpomyia sp.
Family Chironomidae	
Subfamily Chironominae	
	Chironomus c. plumosus
	Polypedilum sp.
	Pseudochironomus sp.
Subfamily Tanypodinae	
	Procladius culiciformis
	Coelotanypus scapularis
	Clinotanypus sp.
	Anatopynia sp.

Table 1 cont.: Benthic macroinvertebrates collected from Sandusky Bay and adjacent waters November 1972 to October 1974

Class Crustacea	
Order Amphipoda	
Family Talitridae	*Hyalella azteca*
Phylum Mollusca	
Class Gastropoda	
Order Pulmonata	
Family Physidae	*Physa* sp.
Family Planorbidae	*Planobula* sp. *Helisoma* sp.
Family Anclyidae	*Ferrissia* sp.
Family Lymnaeidae	*Bulimnaea* sp.
Order Ctenobranchiata	
Family Amnicolidae	*Amnicola* sp.
Family Viviparidae	*Viviparus* sp.
Family Valvatidae	*Valvata* sp.
Family Pleuroceridae	*Pleurocera* sp. *Goniobasis* sp.
Class Pelecypoda	
Family Sphaeriidae	*Pisidium* sp. *Sphaerium* sp.
Family Unionidae	*Anodonta grandis*

TABLE 2

TOTAL NUMBER OF BENTHIC ORGANISMS PER SQUARE METER TAKEN FROM ALL STATIONS IN SANDUSKY BAY AND ADJACENT WATERS NOVEMBER 1972 TO MARCH 1974

Station	November 1972	March 1973	May 1973	June 1973	July 1973	August 1973	September 1973	October 1973	November 1973	December 1973	January 1974	February 1974	March 1974
1	819				402								
2	3,117												
3	3,808				210								
4	3,254				95								
5	918	1,815	344	286	114	191	535	689	728		824		1,035
6	2,601	3,526	1,415	497	707	496	535	632	670		825		929
7	2,373				573								
8	4,477	731	133	172	172	172	631	900	938		1,129		1,262
9	4,098				517								
10	421				306								
11	1,764				1,169								
12	3,271				364								
13	2,015				287								
14	818				211								
15	916				96								
16	172	172	495	612	96	153	536	1,015	1,035		1,243		1,359
17	976	5,977	822	572	937	421	707	1,110	1,225		1,435		1,549
18	1,072				306								
19	727	4,567	1,050	690	535	344	1,264	1,264	1,264		1,493		1,550
20	307				95								
21	632	923	1,242	593	498	229	785	1,147	1,167		1,646		1,667
22	57				19								
23	1,162				133								
24	732				517								
25	1,033				459								
26	1,033				267								
27	1,420				422								
28	57				305								
29	1,243	1,118	3,113	439	249	766	1,224	1,436	1,475		1,837		1,953
30	894				766								
31	632	215	6,724	3,024	478	440	1,244	1,339	1,378		1,704		1,702
32	497				287								
33	387	5,891	4,279	3,464	287	191	944	1,283	1,322		1,647		1,609
34	172												
35	1,506	645	6,475	4,249	613	478	881		1,339				
36	2,970	17,673	6,150	4,077	498	709	889	1,301	1,301				6,150
37					191	363	900	1,111	1,110		1,511		1,454
38	2,282	129	1,679	2,467	421		1,262	1,550	1,531				1,679
39					306	172	785	1,147	1,244				
40					114	57	613		1,187				
41						555	1,263	1,895	1,492				
43						57	229	325	211				
44						57	172	230	344				
Mean	1,476	3,319	2,609	1,624	355	325	818	1,080	1,103		1,390		1,839

TABLE 3

TOTAL NUMBER OF BENTHIC ORGANISMS PER SQUARE METER TAKEN FROM SELECTED STATIONS IN SANDUSKY BAY NOVEMBER 1972 TO OCTOBER 1974

Station No.	Nov. 1972	March 1973	May 1973	June 1973	July 1973	August 1973	Sept. 1973	Oct. 1973	Nov. 1973	Jan. 1974	March 1974	April 1974	May 1974	June 1974	July 1974	August 1974	Oct. 1974	Mean
2	3,117											1,977	1,677	1,422	1,239	1,148	795	1,625
6	2,601	3,526	1,415	497	707	496	535	632	670	825	929	2,162	2,255	1,690	1,493	1,302	843	1,322
11	1,764				1,169							2,296	1,993	1,563	1,462	1,225	863	1,541
17	976	5,977	822	572	937	421	707	1,110	1,225	1,435	1,549	1,908	1,799	1,567	1,435	1,216	813	1,439
21	632	923	1,242	593	498	229	785	1,147	1,167	1,646	1,667	2,333	2,152	1,799	1,632	1,349	958	1,221
23	1,162											1,365	1,403	1,178	1,102	994	747	1,136
29	1,243	1,118	3,113	439	249	766	1,224	1,436	1,475	1,837	1,953	1,229	1,345	1,065	886	764	574	1,218
33	387	5,891	4,279	3,464	287	191	944	1,283	1,322	1,647	1,609	2,009	1,620	1,320	1,122	1,062	739	2,279
34	172											344			298		171	246
35	1,506	645	6,475	4,249	613	478	881		1,339			2,399	2,252	1,825	1,653	1,387	1,033	1,909
36	2,970	17,673	6,150	4,077	498	709	889	1,301	1,301		6,150	2,219	2,073	1,747	1,543	1,311		3,374
37					191	363	900	1,111	1,110	1,511	1,454	2,196	1,972	1,750	1,481	1,262	835	1,241
38	2,282	129	1,679	2,467	421		1,262	1,550	1,531		1,679	2,100	2,066	1,765	1,519	1,214		1,547
Mean	1,568	4,485	3,147	2,045	559	457	903	1,196	1,238	1,484	2,123	1,887	1,876	1,558	1,290	1,186	761	

species comprised 90% of the benthic macroinvertebrate fauna. Although 31 genera were recorded from approximately 300 samples, some appeared in only one sample while others, such as the mollusks, were identified only from empty shells. While some of these organisms have been reported in the bay, we have no judgement as to whether they are denizens or were washed into the bay with the very high water that was characteristic of the period in which they were recorded. High water made it impossible to completely sample the littoral zone of the south shore where there are surely to be many forms of aquatic larvae of insects as well as some crustaceans. Rip-rap stone along a section of the shore contains many niches which no doubt are filled with invertebrates that defy quantitative and qualitative routine sampling, particularly during periods of high water. A taxonomic list of the benthic invertebrates found in Sandusky Bay is shown in Table 1.

Tables 2 and 3 summarize the number of benthic organisms collected at each station per month. Included in Table 2 are the two saturation sampling periods, November 1972, and July 1973, in which all stations were sampled. Table 3 contains a listing of seven near-shore stations (nos. 2, 6, 11, 17, 23, 29 and 37), five mid-bay stations (21, 33, 35, 36, and 38) and the Sandusky River mouth (no. 34) for the entire study period. The larger standing crop of benthic organisms in the mid-bay area is probably the result of a more stable habitat. The shallower shore and near-shore area is more affected by wind and fluctuating water levels.

The highest number of organisms was collected at Station 36. The mean number of benthic organisms collected at Station 36 was $3374/m^2$ with a monthly high of 17,673/m^2 in March 1973. Station 36 is probably the most sheltered and thus the most stable habitat in the offshore area of Sandusky Bay. In the western end of the bay, Station 33 at Muddy Creek Bay, yielded the most benthic organisms. The mean number of organisms collected at this station was 2279/m^2 with a maximum of 5,891/m^2 also in March 1973.

There was a definite seasonal variation in the number of organisms collected at all stations (fig. 2). The largest number of organisms was collected in March 1973 with monthly decline in number to a low in August 1973. From August 1973, to March 1974 there was a monthly increase in the number of organisms collected, then another decline thru October 1974. The low density of organisms collected during July and August is probably the result of the emergence of chironomids (midges) and the natural mortality of oligochaetes. During the months of July and August, collections at all stations showed the absence of one or more of the dominant species of oligochaetes and chironomids. From September to March all such dominant populations were collected in each sample.

The immature oligochaetes are most abundant, particularly in the mid-bay stations. Adult oligochaetes are likewise more abundant in the mid-bay area. Station 33 (mouth of Muddy Creek Bay) was the only mid-bay station in which the chironomids outnumbered the oligochaetes. The chironomids dominated the samples collected at Station 33 from September 1973 to January 1974. At the nearshore Stations 29 and 31, chironomids outnumbered the oligochaetes from July 1973 to November 1973.

The data for the rest of the Bay stations do not indicate any geographic preference by any species. All species seem to be rather widely distributed

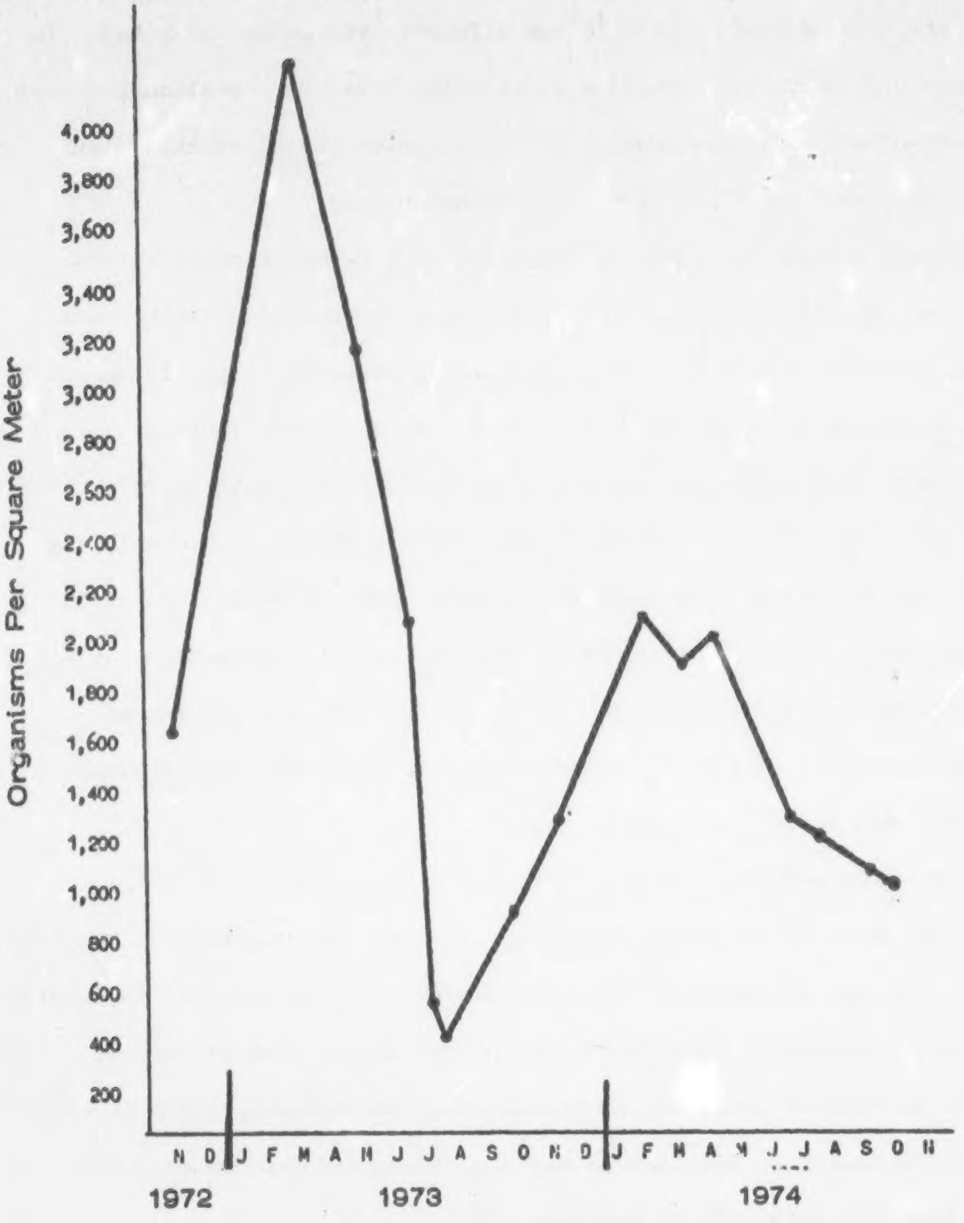

Figure 2. Monthly Mean Number of Benthic Organisms in Sandusky Bay.

throughout the western basin of Sandusky Bay. The data do not show any correlation between the density of one species against another, even seasonally.

The characteristics of the benthic fauna seem to be homogeneous for the western basin. The benthic fauna from Station 37 on the north shore of the western basin are very similar to that from the south shore; the same populations are present and in approximately the same density relationship. The oligochaetes dominate the community, and the total density of organisms is lowest in July and August.

The benthic data for Station 39 located at the junction of Pickerel Creek and U. S. Route 6 indicates that this station can be considered as an inland extension of the bay. A comparison of the total organisms per month in the creek with the mean number of organisms collected in the bay for the same month shows this similarity. Station 40, located in Schertz Ditch at U. S. Route 6 is another inland extension of the bay. A comparison of the total number of benthic organisms collected per month at Station 40 with the mean number of similar organisms collected in the bay indicates that the standing crop at Station 40 is less. During the month of August 1973, there were no chironomids collected at this station. The chironomids reappeared in the September and November 1973 collections.

Station 41, located at the outflow of Miller Blue Hole, is different from the other bay and inshore stations. The substratum is primarily calcareous marl (tufa) with small patches of field drained silt. Large masses of the filamentous alga, *Cladophora* are attached to the marl. The dominant benthic species is the crustacean amphipod, *Hyalella azteca*, a common periphytic grazer. The benthic community is probably more extensive in species number than recorded because of the difficulty in dislodging organisms from the crevices in the marl.

Stations 43 and 44, located at the junction of Pickerel Creek and Ohio Route 247 and Schertz Ditch and Ohio Route 247 respectively, are inland (south) far enough that they are not influenced by bay water. The substratum is shelving rock and silt laden pools, very characteristic of the small streams in northwestern Ohio. Both showed evidence of drying up, except for some pools, during the summer of 1973. Some immature oligochaetes were recorded from Schertz Ditch in August but no adults were recorded. At Pickerel Creek there was a complete absence of oligochaetes. Three species of chironomids were present but in lower densities than those of the bay. The bryozoan, *Plumatella*, was found in both stations in August.

DISCUSSION

The Oligochaetes, *Limnodrilus hoffmeisteri* and *Branchiura sowerbyi* are able to withstand a wider range of environmental conditions than all other freshwater tubificids (Brinkhurst, 1971). These tubificids can withstand periods of oxygen deficiencies, including complete anaerobic conditions, for up to four weeks under laboratory conditions. They therefore have the ability to be faculative anaerobes for short periods of time. All of these worms burrow into the sediment; some constructing tube cases. They ingest mud and extract both soluable nutrient material and microorganisms. This hard nature makes them well adapted to the environmental stresses in the bay.

The oligochaetes in Sandusky Bay have a one-year life cycle. Brinkhurst (1971) reported the peak of breeding period for this group occurs when the water temperature reaches 15°C. This temperature normally occurs in May in the bay. The species present in the bay habitats appear to be present the year-round both in the adult and juvenile form. There is no evidence from the available data to indicate a preponderance of either adult or immature forms over one another.

Of the three most abundant species of Chironomids in Sandusky Bay, *Procladius curiciformus* and *Coelotanypus* sp. are carnivorous predators while *Chironomus c. plumosus* is a herbivore which constructs a definite burrow (Johannsen, 1969). According to Oldroyd (1964), *Chironomus* will spin a cone of silk that projects into the water. Plankton and other organisms become stuck to the silk and are devoured along with the silk. The larvae then spins another cone and repeats the process. It may also merely extend from the burrow and graze on surrounding microorganisms. Body undulations by the larvae carry water down into the burrow-tube to the gills located in the posterior body segment. The genus *Chironomus* feeds primarily on planktonic diatoms, algae, aquatic plant tissue, and decaying organic matter. *Procladius* and *Coelotanypus* belong to the subfamily Tanypodinae which, according to Johannsen, (1969), do not construct burrows. They may inhabit the burrows of those species that do construct. The members of this subfamily are predaceous, feeding largely on other chironomids.

Both oligochaetes and chironomids are denizens of aquatic environments that are highly eutrophic. They prefer a substrate of mud and silt that contains a high amount of organic material. Sandusky Bay offers such suitable niches for these organisms.

The only other comprehensive study of the benthos of Sandusky Bay was conducted by the Franz Theodore Stone Laboratory of Ohio State University in August 1938 (Chandler, 1938). Chandler reported a mean benthic population of $1450/m^2$. This number compares well with $1186/m^2$ for August 1974. Chandler found that the dipterans were far more abundant than the oligochaetes. A dramatic shift from chironomids to oligochaetes appears to have taken place in the past 35 years. Chandler also observed the substrate on which the benthos grew and noted that oligochaetes did best on silt, whereas dipterans preferred sand and gravel or hard clay. The silt-rich sediment which now covers most of the mid-bay bottom tends to favor the large populations of oligochaetes which now dominate the area.

ACKNOWLEDGEMENTS

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ABSTRACT

ABUNDANCE AND POPULATION TRENDS OF SANDUSKY BAY FISHES

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The fish population of Sandusky Bay has undergone a dramatic change in response to increased environmental stress. Mill dams built in the early 1800's blocked the spawning migration of the northern pike, muskellunge and walleye. Deforestation and plowing of prairie land in the Sandusky Bay watershed resulted in increased turbidity and siltation of spawning grounds. Draining and dyking of marshes further decreased the spawning sites available. Intense commercial fishing resulted in the overexploitation of several species including the northern pike, smallmouth and largemouth bass, by 1900. Further stress to native species resulted from the introduction of carp and goldfish in the late 1800's which competed for the resource base.

A comparison of species abundant in 1830 to those fish abundant in 1940 and 1974 shows a dramatic change in the fish population. The abundant species in 1830 were white bass, walleye, northern pike, muskellunge, catfish and blackbass (Klippart, J.H. In Ohio Fish and Game Commisssion, Annual Report..., 1877). The abundant species in 1940 were white crappie, white bass, gizzard shard, carp, goldfish, bullheads and freshwater drum (Edmister, J.O., Fish and Fisheries of Sandusky Bay..., 1940). Data from the present study indicates that the same species abundant in 1940 are presently abundant, but changes in relative abundance have occurred.

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INTRODUCTION

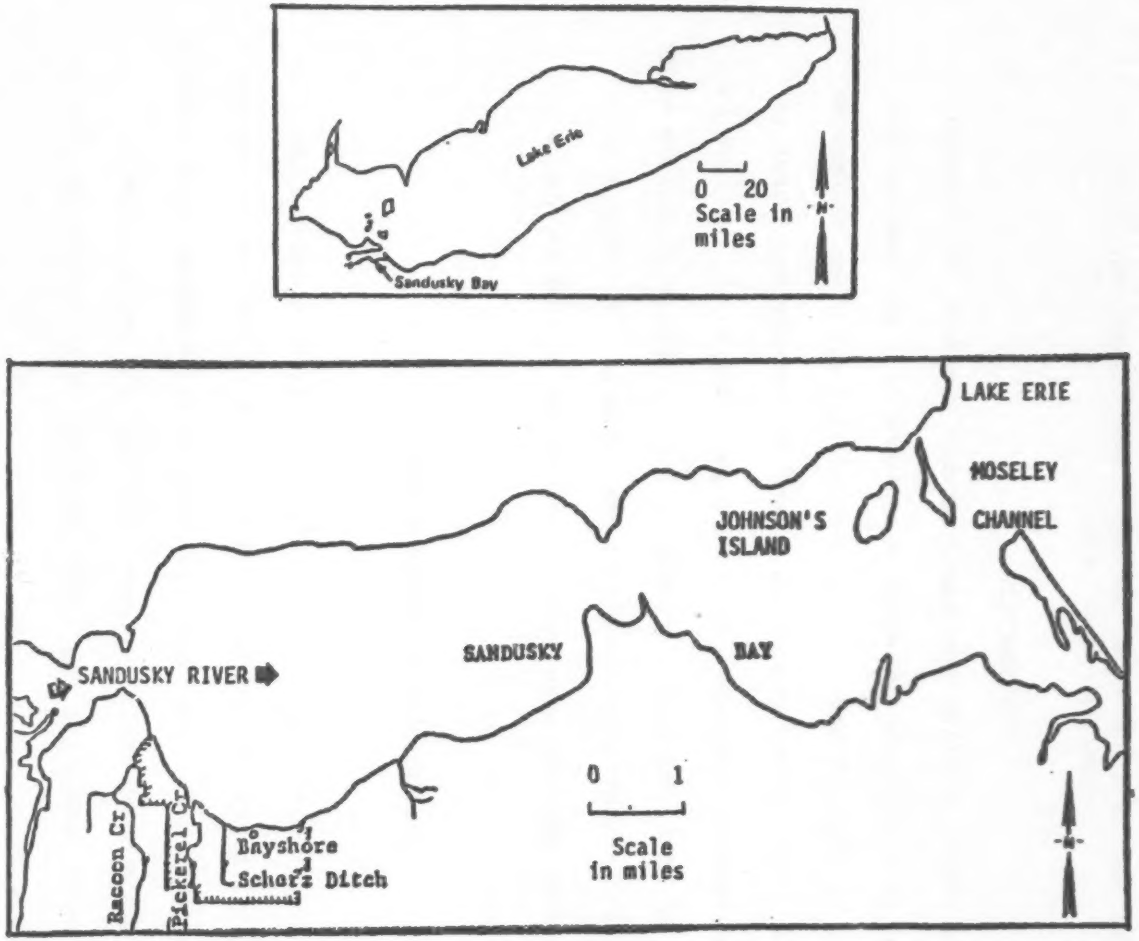
The present fisheries study was conducted from November 1972 through November 1974 as part of an environmental assessment of a proposed nuclear-power plant site on Sandusky Bay. The purpose of this study was to provide insight into the abundance and population trends of Sandusky Bay fishes in response to environmental changes. The fish populations in the bay have been altered significantly in the past 150 years because of increased environmental stress. Many factors have contributed to these stresses. The following discussion will deal with these factors in some detail as they relate to particular species.

DESCRIPTION OF SANDUSKY BAY

Morphometry

Sandusky Bay is located on the south shore of Lake Erie between the Western and Central basins (figure 1). The long axis of the bay is oriented toward the east north-east. The major tributary is the Sandusky River draining 3,680 sq km. Over a dozen smaller streams flow into the bay draining an additional 911 sq km (table 1). The entire drainage basin is estimated to be 4,591 sq km (figure 2).

The bay has a maximum length of 23.93 km, a maximum width of 7.63 km and a mean depth of 1.61 m.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MOSELEY
CHANNEL
JOHNSON'S ISLAND
SANDUSKY
BAY
SANDUSKY RIVER
0 1
Scale in miles
N
Bayshore
Schorz Ditch
Racoon Cr
Pickerel Cr

FIGURE 1. LOCATION OF SANDUSKY BAY AND PROPOSED POWER PLANT SITE

Table 1: Drainage areas of streams tributary to Sandusky Bay

Tributary	Area (sq km)
Western Basin	4,314
Sandusky River (includes Yellow Shale and Green Creeks	3,680
South Creek	57
Muddy Creek (includes Little Muddy Creek)	287
Raccoon Creek	88
Pickerel Creek	119
Stream thru York	
Stream thru White's Landing	
Little Pickerel Creek	83*
Eastern Basin	277
Cold Creek	23
Mills Creek	109
Pipe Creek	75
Plumbrook Creek	18
Marblehead Peninsula Drainage	52+
Total	4,591

(Ohio Department of Natural Resources, 1967; Battelle, 1974)

*Estimated value for all three streams.
+Estimated value.

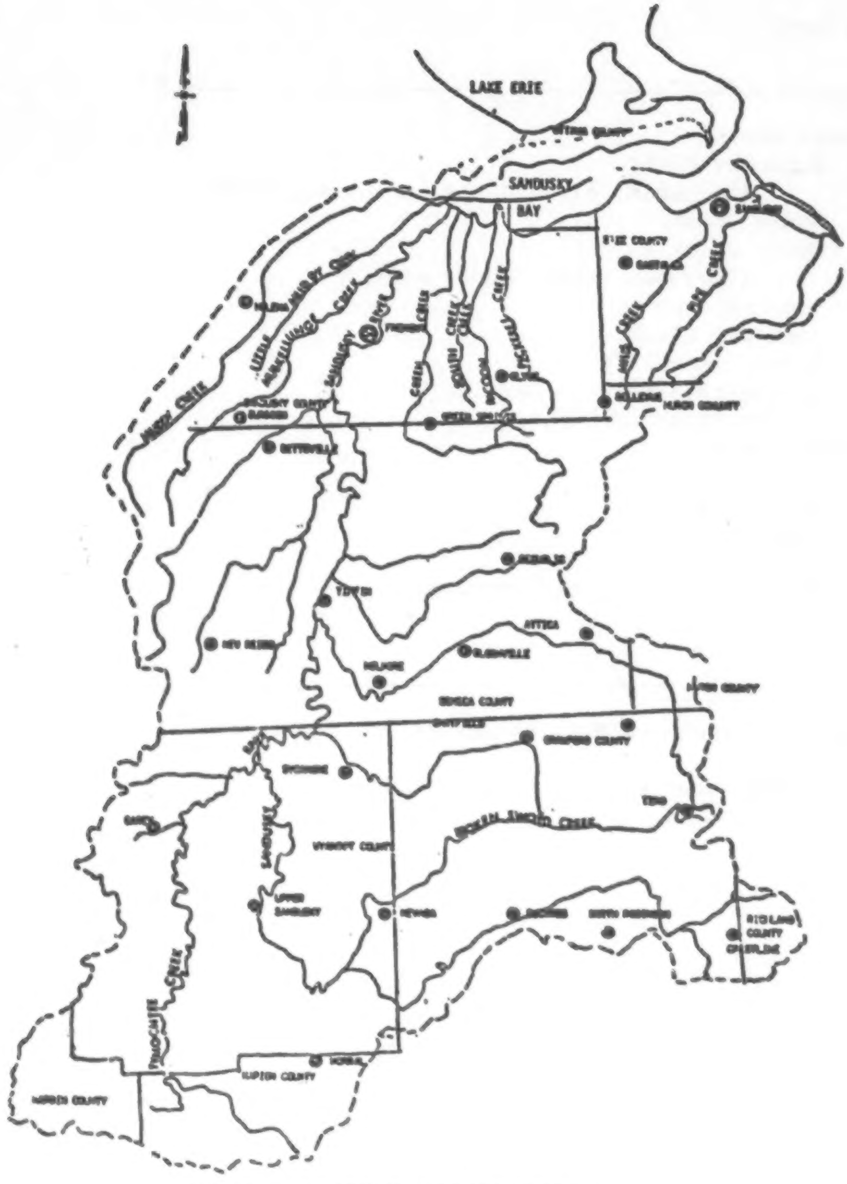

LAKE ERIE
OTTAWA COUNTY
SANDUSKY
BAY
ERIE COUNTY
SANDUSKY COUNTY
HURON COUNTY
SENECA COUNTY
CRAWFORD COUNTY
WYANDOT COUNTY
RICHLAND COUNTY
MUDDY CREEK
LITTLE MUSKELLUNGE CREEK
SANDUSKY
GREEN CREEK
SOUTH CREEK
RACCOON CREEK
PICKEREL CREEK
MILLS CREEK
PIPE CREEK
BROKEN SWORD CREEK
TYMOCHTEE CREEK
FREMONT
CLYDE
BELLEVUE
GREEN SPRINGS
TIFFIN
ATTICA
BLOOMVILLE
MELMORE
UPPER SANDUSKY
NEVADA
BUCYRUS
CRESTLINE
TIRO
SYCAMORE

FIGURE 2. SANDUSKY BAY WATERSHED

Sampling Sites

Thirty-two sampling sites were located in the southern half of the western basin of Sandusky Bay (figure 3). One station was located on the north shore of the western basin. A transect, consisting of seven stations, ran from the mouth of the Sandusky River to the mouth of Sandusky Bay (figure 4).

ENVIRONMENTAL FACTORS

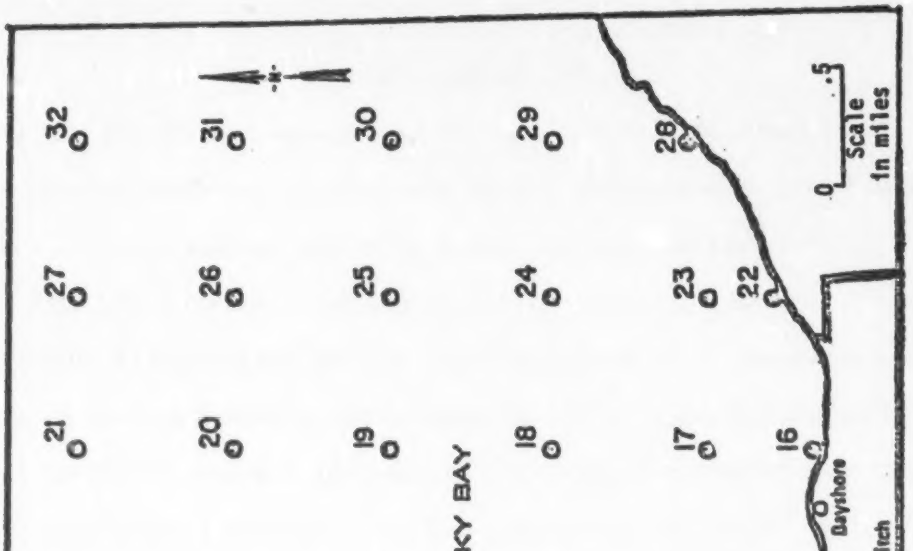
The changes in land use have produced changes in the bay and tributary streams. The formerly clear waters now carry an increased load of suspended and dissolved solids. Average turbidity of the surface water in 1974 was 22.1 JTU. Average turbidity of the bottom water was 33.2 JTU with the highest values occuring in the spring and summer. The suspended and dissolved materials are a direct result of erosion and increased run-off on the farm lands, once forests and prairies. The increased suspended solids caused the aquatic vegetation to decrease and made spawning grounds less productive. The vegetation is now limited to the marshes and isolated portions of the bay. The vegetation in many of the marshes is unavailable to the fish population because of extensive dyking.

FISH POPULATIONS

Introduction

Twenty-three species of fish, representing 13 families, were collected in Sandusky Bay from November 1972 through November 1974. A total of 4,882 individuals was captured during the study. Table 2 lists the species captured and the number per month of collection.

FIGURE 3. SANDUSKY BAY SAMPLING STATIONS ADJACENT TO PROPOSED POWER PLANT SITE


N
SANDUSKY BAY
Bayshore
Scherz Ditch
Pickerel Cr.
Raccoon Cr.
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Scale in miles
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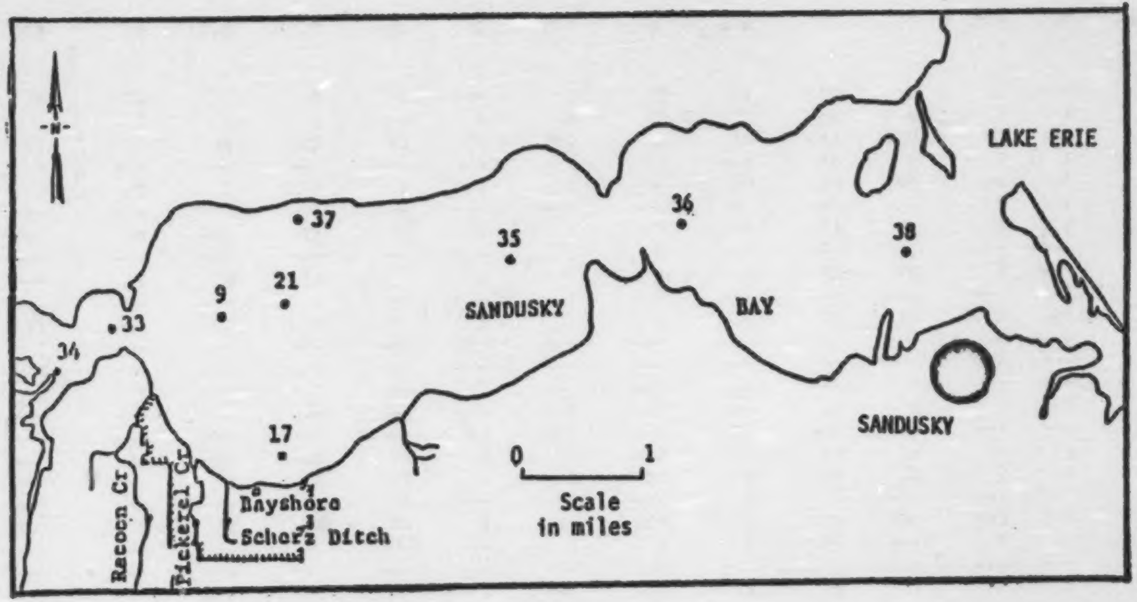
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Bayshore
Scherz Ditch
Racoon Cr
Pickerel Cr

FIGURE 4 POSITION OF SAMPLING STATIONS IN SANDUSKY BAY

Table 2: Species composition of fishes taken from Sandusky Bay*
November, 1972 - November, 1974

Species	Nov 1972	March 1973	June 1973	July 1973	Aug 1973	Sept 1973	April 1974	May 1974	June 1974	July 1974	Aug 1974	Oct 1974	Nov 1974	Total
Longnose gar	—	—	—	—	—	—	—	2	17	4	2	—	1	26
Bowfin	—	—	—	—	—	—	—	—	—	2	—	—	—	2
Alewife	—	—	—	—	—	—	2	7	2	—	—	1	31	43
Gizzard shad	153	2	23	46	49	9	84	264	102	75	596	442	108	1953
Northern pike	—	—	—	—	1	—	—	—	2	1	—	—	1	5
Goldfish	—	—	3	5	2	—	6	10	2	24	22	8	12	94
Carp	—	—	28	14	12	4	7	33	23	48	54	19	24	266
Emerald shiner	—	—	—	—	—	—	—	—	20	—	—	—	—	20
Spottail shiner	—	—	—	—	—	—	4	19	—	5	4	7	1	40
Quillback	—	2	—	—	—	1	—	—	—	—	1	—	—	4
White sucker	3	—	—	—	—	—	—	—	—	—	—	—	—	3
Redhorse	1	—	—	—	—	—	—	—	—	—	—	—	—	1
Brown bullhead	11	—	1	—	—	2	3	4	9	72	30	74	88	294
Black bullhead	—	—	—	2	—	—	1	—	—	—	—	—	—	3
Channel catfish	—	1	4	13	5	3	7	3	1	17	4	1	—	59
Trout-perch	—	—	—	—	—	—	1	2	—	—	1	—	—	4
White bass	301	15	—	11	11	6	9	11	6	13	20	4	2	409
Largemouth bass	—	—	—	—	—	—	—	—	—	—	—	1	—	1
White crappie	11	2	5	6	6	5	11	—	56	26	66	56	54	304
Black crappie	—	—	—	—	—	—	—	18	—	10	5	3	1	37
Yellow perch	11	5	36	69	87	36	390	88	59	47	120	63	45	1056
Walleye	7	3	1	3	4	5	3	1	2	1	9	9	3	51
Freshwater drum	18	14	11	9	6	—	7	73	23	40	5	1	—	207
TOTAL	516	44	112	178	183	71	535	535	324	383	941	689	371	4882

* Captured by trawl, commercial seine, gill net, and fyke net.

The fish population of Sandusky Bay is dominated by Gizzard shad *(Dorosoma cepedianum)* and Yellow perch (*Perca flavescens*). Gizzard shad comprised 40% of the total catch; Yellow perch comprised 22%. Other species contributing more than 1% were: White bass (*Morone chrysops*), 8.4%; Carp (*Cyprinus carpio*) and Goldfish (*Carassius auratus*), 7.4%; White crappie (*Pomoxis annularis*),6.2%; Brown bullhead ((*Ictalurus nebulosus*), 6.0%; Freshwater drum (*Aplodinotus grunniens*), 4.2%; Channel catfish (*Ictalurus punctatus*), 1.2%; and Walleye (*Stizostedion v. vitreum*), 1.0%. Figure 5 graphically illustrates these relationships.

The fish of Sandusky Bay can be grouped into three catagories: rough, game and forage. In the present study the forage fish were selected against by the mesh size of the gear used. In 1973, the smallest mesh used was one inch. In 1974, the smallest mesh was one-half inch; even the one-half inch mesh catches only the larger forage fish. A seine with smaller mesh size could have been used to obtain samples of forage fish. This method was not used for several reasons. The main reason was the unsuitability of the bay for pulling a seine. Much debris and many large rocks are on the shore line with no location available to pull the net out of the water. Communication with Prof. Milton B. Trautman (1975) indicated that the Bluntnose minnow (*Pimephales notatus*), the Spotfin shiner (*Notropis spilopterus*), the Spottail shiner (*Notropis hudsonius*) and the Emerald shiner (*Notropis atherinoides*) are presumed present and abundant. The Emerald shiner, however, may be decreasing. In the present study only Emerald shiners and Spottail shiners were captured. Also contributing to the forage base are the young Gizzard shad. This, then, is the forage base.

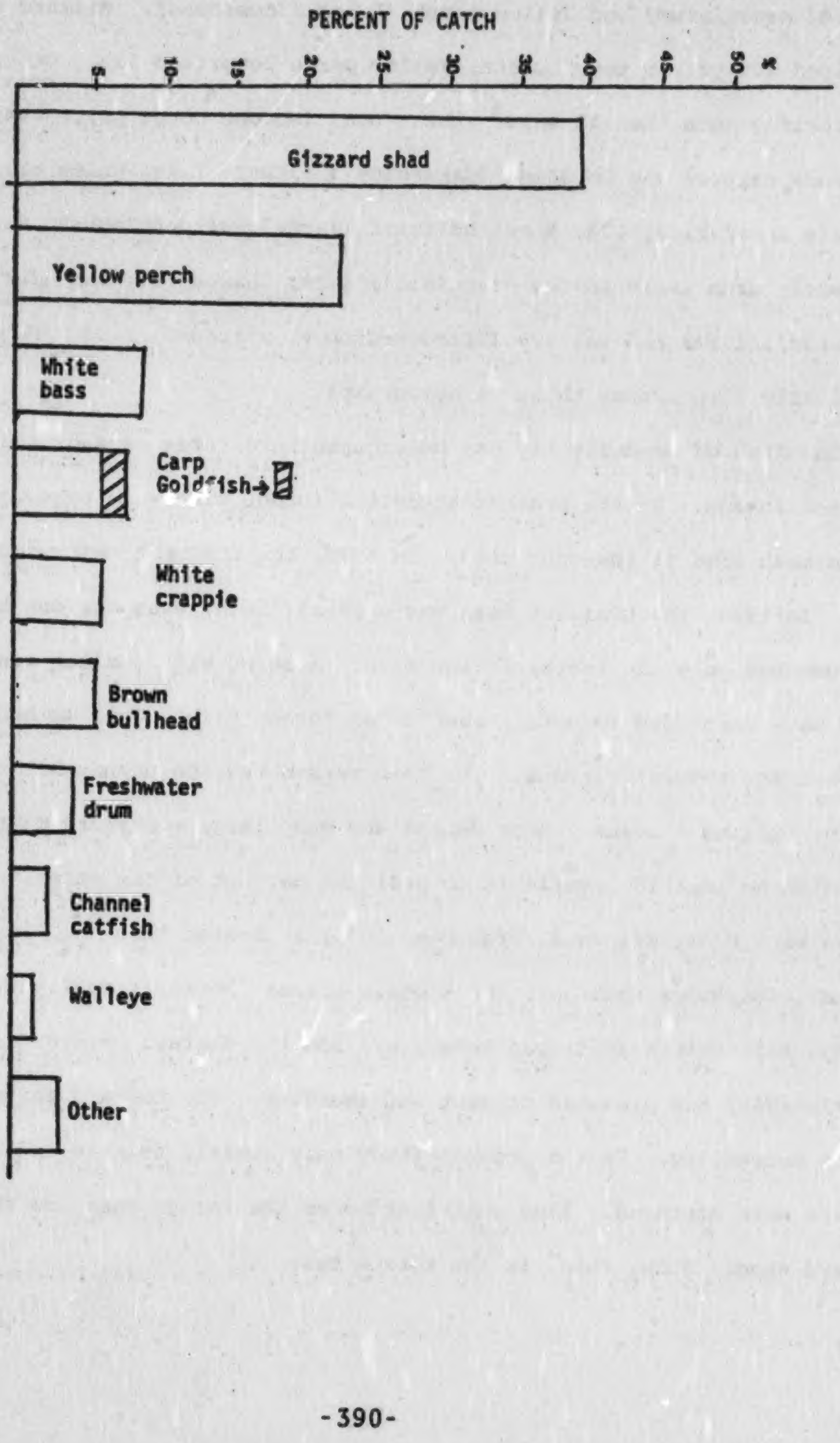

FIGURE 5 SPECIES COMPOSITION, NOVEMBER 1972–NOVEMBER 1974 (Percent of Total Catch)

The game species taken in Sandusky Bay were: Northern pike (*Esox lucius)*, Brown bullhead (*Ictalurus nebulosus)*, Black bullhead (*Ictalurus melas)*, Channel catfish (*Ictalurus punctatus)*, White bass (*Morone chrysops)*, Largemouth bass (*Micropterus salmoides)*, White crappie (*Pomoxis annularis)*, Black crappie (*Pomoxis nigromaculatus)*, Yellow perch (*(Perca flavescens)*, and Walleye (*Stizostedion v. vitreum)*. These species were 35.8% of the species composition. The rough and non-game fish taken were: Longnose gar (*Lepisosteus osseus)*, Bowfin (*Amia calva)*, Alewife (*Alosa pseudoharengus)*, Gizzard shad (*Dorosoma cepedianum)*, Goldfish (*Carassius auratus)*, Carp (*Cyprinus carpio)*, Quillback (*Carpoides cyprinus)*, White sucker (*Catostomus commersoni)*, Redhorse sp. (*Moxostoma* sp.), Trout-perch (*Percopsis omiscomaycus)* and Freshwater drum (*Aplodinotus grunniens)*. These species make up 63.0% of the species composition. The remaining 1.2% are the forage fish, Emerald shiner and Spottail shiner.

Figure 6 illustrates seasonal fluctuations in the Sandusky Bay fish population. August was the peak month for both 1973 and 1974. A smaller peak occurred in April and May 1974. Figure 7 and 8 show the close correlation between the total species abundance peaks and the abundance peaks of Gizzard shad and Yellow perch. The April-May peak is probably due to the influx of Yellow perch entering the bay to spawn. Yellow perch spawn from mid-April to May (Trautman, 1957). Also, there is an April-May peak for Gizzard shad. Gizzard shad spawn in June and July in small streams and drainage ditches (Bodula, 1964). Possibly the shad are moving inshore, preparing to spawn in the small streams and ditches tributary to the bay. They return again in August causing a high peak in the abundance graph. A large portion of the peak is due to the influx of young Gizzard shad. The August lengths are predominantly less than 130mm. In June the lengths were between 200-400mm.

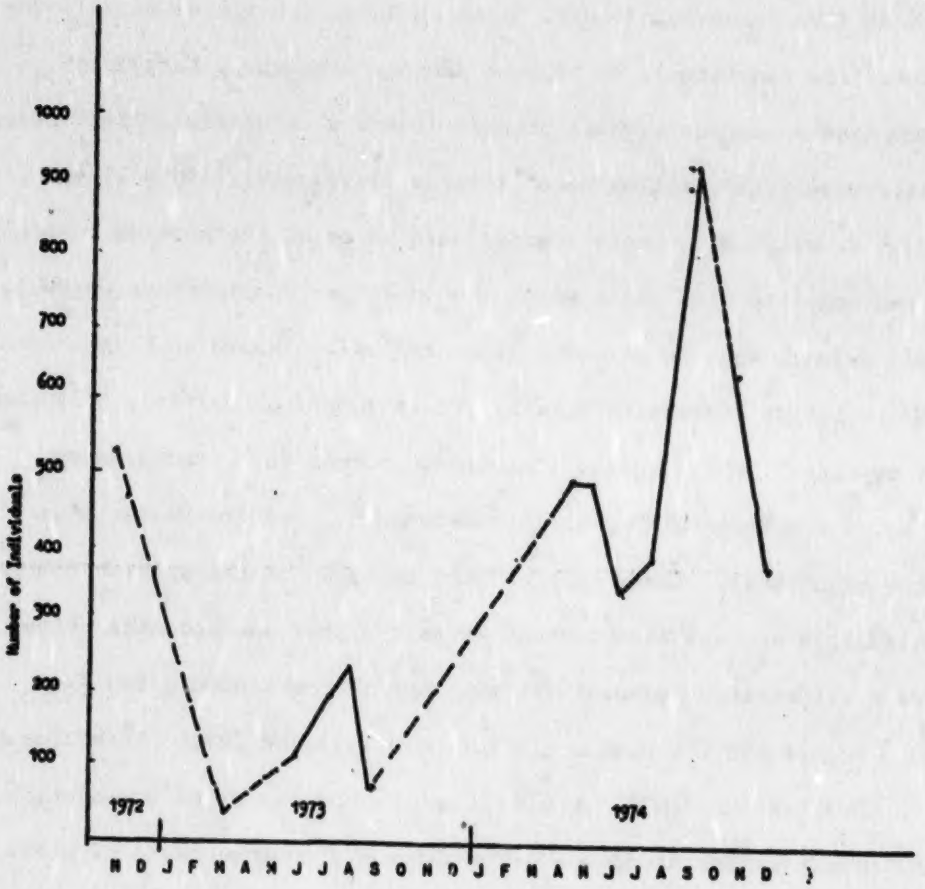

FIGURE 6. TOTAL NUMBER OF FISH CAUGHT PER MONTH OF STUDY

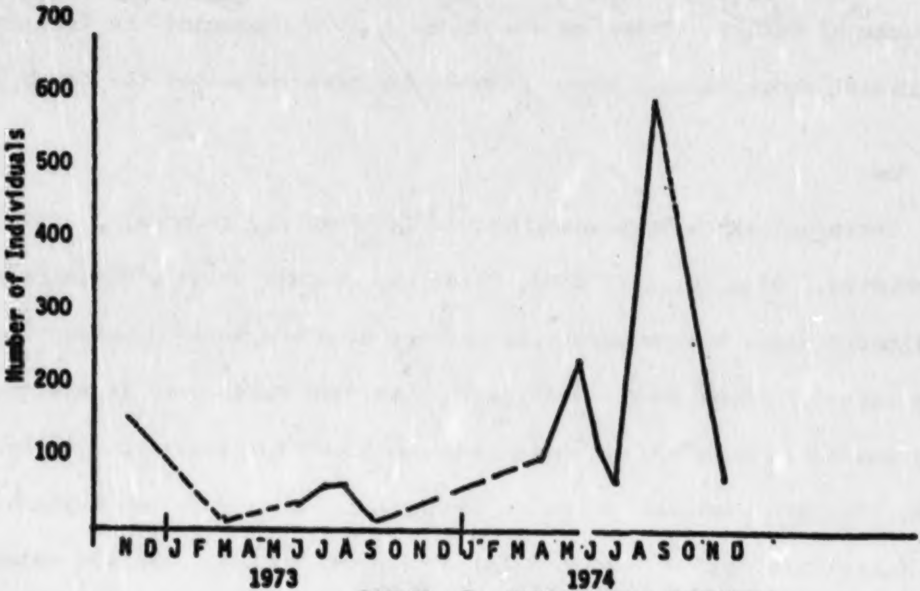

FIGURE 7. GIZARRD SHAD ABUNDANCE

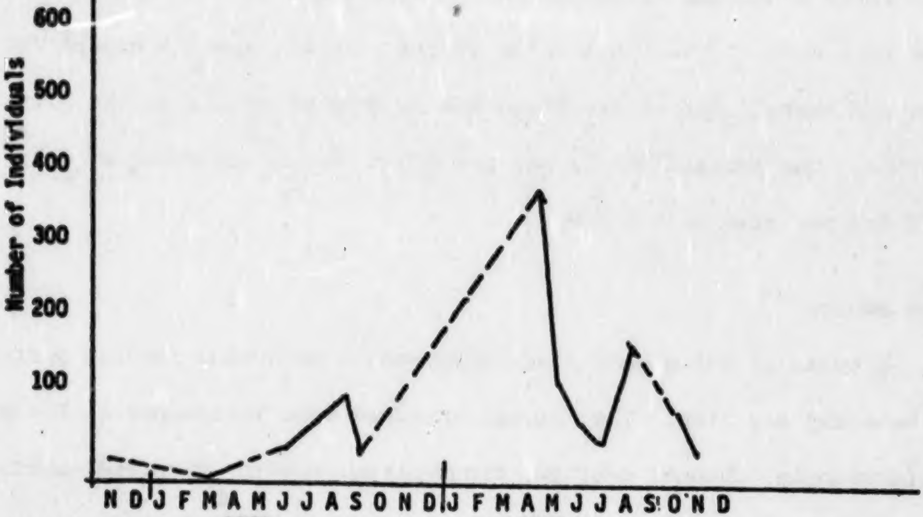

FIGURE 8. YELLOW PERCH

More fish were caught in 1974 than in 1973. This may be attributable to the placement of the gill net formerly at station 21 at station 5 (mouth of Pickerel Creek). Trawling was begun in 1974 replacing the fyke net and commercial shore seine. These changes may have increased the catch efficiency.

Fry Tow

Ichthyoplankton tows were made in Sandusky Bay from May 3, 1974 to October 24, 1974. Gizzard shad, Goldfish, Emerald shiner, White bass, Smallmouth bass, Yellow perch, Freshwater drum and various unidentifiable eggs were taken in these tows. Smallmouth bass were taken only in the fry tows. This was to be expected as adult bass are known for their ability to avoid nets. Gizzard shad was the major constituent species in the fry tows. Unidentifiable eggs were second followed by White bass, Emerald shiner, Freshwater drum, and Yellow perch. Smallmouth bass and Goldfish contributed less than 0.1% of the total catch (table 3). All species except for Smallmouth bass and Emerald shiner are discussed in greater detail in the Historical Section. The Emerald shiner was prominent during the month of July averaging 60.2 fry per five minute tow.

Food Habits

A total of 285 stomachs was analyzed to determine feeding preferences of Sandusky Bay fish. The species examined were Yellow perch, Black and White crappie, Channel catfish, Trout-perch, Bowfin, Carp and Goldfish, White bass, Freshwater drum, and Brown bullhead. The frequency of occurrence of food organisms in these species of fish is given in Table 4.

The most frequently occurring food organisms in Yellow perch were Diptera and fish. Price (1963) found Diptera, Amphipoda and Tricoptera

Table 3: Analysis of fry net tow at Sandusky Bay

Species	May 31 1974		June 26 1974		July 24 1974		Aug 21 1974		Oct 4 1974		Oct 24 1974		Total	Per
	Number	Mean	Number	Mean	Number	Mean	Number	Mean	Number	Mean	Number	Mean	Number	cent
Eggs	4,568	571	7,462	932.7	---	---	---	---	---	---	---	---	12030	28.9
Gizzard shad	27,035	3,379	740	92.5	1,228	153.5	62	7.7	7	0.9	3	---	29075	67.0
Goldfish	---	---	4	0.5	---	---	---	---	---	---	---	---	4	0.1
Emerald shiner	---	---	---	---	482	60.2	9	1.1	1	0.1	6	---	498	1.1
White bass	---	---	878	109.7	76	9.5	11	1.3	---	---	---	---	965	2.2
Smallmouth bass	---	---	3	0.4	---	---	---	---	---	---	---	---	3	0.1
Yellow perch	245	30.6	---	---	---	---	---	---	---	---	---	---	245	0.6
Freshwater drum	478	59.7	10	1.2	---	---	---	---	---	---	---	---	488	1.1
TOTAL	32,326	---	9,097	---	1,787	---	82	---	8	---	9	---	43309	---

*Mean number per tow

Table 4: Frequency of occurrence of food organisms in Sandusky Bay fish

Species	Yellow perch	Crappies	Channel catfish	Trout perch	Bowfin	Carp and Goldfish	White bass	Freshwater drum	Brown bullhead
No. of Fish	141	57	12	3	1	8	7	36	20
Empty	30.5	19.3	16.7	0.0	0.0	0.0	28.5	41.7	70.0
Chironomus	25.5	38.4	25.0	33.3	0.0	0.0	0.0	16.7	80.0
Procladius	8.5	8.8	0.0	33.3	0.0	0.0	0.0	2.8	14.3
Coelotanypus	3.5	3.5	0.0	33.3	0.0	0.0	0.0	0.0	4.8
Chironomid Larvae	17.0	26.3	25.0	99.9	0.0	12.5	0.0	41.7	38.1
Adult *Diptera*	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oligochaete Setae	17.0	12.3	17.9	16.7	33.3	37.5	0.0	11.1	0.0
Zooplankters	17.7	26.3	0.0	0.0	0.0	0.0	0.0	11.1	0.0
Phytoplankters	1.4	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diatoms	8.2	1.7	8.3	0.0	0.0	62.5	0.0	2.8	0.0
Plumatella	0.7	0.0	0.0	0.0	0.0	0.5	0.0	0.0	9.5
Notropis hudsonius	8.5	5.3	8.3	0.0	0.0	0.0	28.5	16.7	4.8
Perca flavescens	1.4	0.0	8.3	0.0	0.0	0.0	0.0	11.1	0.0
Aplodinotus gr nniens	1.4	0.0	16.7	0.0	0.0	0.0	0.0	0.0	9.5
Unidentified Fish	27.0	12.3	50.0	0.0	99.9	0.0	42.9	11.1	47.6
Unidentifiable	24.8	35.1	41.7	0.0	0.0	99.9	28.5	25.0	57.1

to be the major food organisms of Yellow perch. Price, however, collected the fish for his 1958 study from the Bass Island area as well as from Sandusky Bay. Tricoptera and Amphipoda were not found in the bay during the present study, nor were they recorded by Chandler and Bodelas (1938). Wolfert and Hiltunen (1967) reported these organisms as present but scarce. Apparently the Sandusky Bay Yellow perch population has not changed its food habits, still feeding on the unchanged benthic population. Tubb (1973) studied the food habits of several species of Sandusky Bay fish. Tubb also found Diptera and fish to be major food items in Yellow perch. White crappie and Black crappie were lumped together because of individually small sample size and close taxonomic relationship. The crappies were found to feed primarily on Diptera. Oligochaetes and fish were secondarily important food items. Neither Price (1963) nor Tubb (1973) studied the food habits of the crappie.

The Channel catfish in Sandusky Bay feed predominantly on fish and Diptera. Tubb (1973) found dipterians, fish and cladocerans to be the primary forage items. Price (1963) listed Diptera, Ephemeroptera, Tricoptera and Cladocera to be major food items. Since Ephemeroptera and Tricoptera were not found to be present in the bay during 1972-1974, nor in 1938 (Chandler and Bodelas, 1938), and only 11 specimens from these two taxonomic groups were found in 1963 (Wolfert and Hiltunen, 1967) one may assume that the fish which ate these organisms were either captured in the Bass Island region or had been feeding outside of Sandusky Bay.

Only three trout-perch were analyzed in 1974. All stomachs contained chironomid larvae. *Chironomus, Procladius, Coelotanypus* and Oligochaeta occurred with equal frequency. Price indicated Diptera as the major forage item with Cladocera and Amphipoda being of secondary importance. Amphipoda were not reported in the benthic fauna from Sandusky Bay in the present study, nor in Chandler and Bodelas' 1938 study, and Wolfert and Hiltunen (1967) found Amphipoda present at four scattered stations, no more than six to a station. Thus fish from Sandusky Bay at the time of Price's study were not feeding on Amphipoda in Sandusky Bay but in the Island area. Diptera, then, is and was the major forage item for trout-perch in Sandusky Bay. Cladocerans and other zooplankters were available in Sandusky Bay, but were not utilized. This may be an artifact of sample size.

Only one Bowfin was taken in Sandusky Bay. It contained only fish. Carlander (1969) states that Bowfin feed mainly on fish and crayfish.

Carp and Goldfish were combined because of small sample size and the close taxonomic relationship. Diatoms were found to be the major forage item with oligochaetes of secondary importance. The basic food of the Carp is chironomids, zooplankton, and phytoplankton (Carlander, 1969). Goldfish, however, feed mostly on phytoplankton (Carlander, 1969).

White bass captured during 1974 and analyzed for food preference were found to be feeding exclusively on fish. Both Tubb (1973) and Price (1963) found fish to be the major food organism for White bass. The feeding habits of the White bass do not appear to have altered since Price's study of 1958.

Freshwater drum consumed Diptera and fish during the present study. Tubb (1973) also found the Freshwater drum to be feeding primarily on Diptera and fish. Price indicated Diptera, Amphipoda, Ephemeroptera, and Cladocera as major food items. As previously stated, even at the time of Price's study, Ephemeroptera and Amphipoda were not reported as common in Sandusky Bay benthic fauna. Therefore, it is felt that there has not been a major shift in the food habits of the Freshwater drum since 1958, but there is a continuing utilization of alternate food sources. Trautman (1957) states that a shift in the food habits of the Freshwater drum occurred before 1910. Snails and clams were the principal food of the Freshwater drum but these populations have been destroyed by silting and pollution. Crayfishes, fishes and insects are now the principal food organisms.

Brown bullhead stomachs were found to contain primarily Diptera and secondarily fish. The Brown bullhead feeds primarily on insects, fish, fish eggs, molluscs and plants (Carlander, 1969). Since molluscs and plants are in short supply in Sandusky Bay, the diet of the Brown bullhead is narrowed by available forage to the Diptera and fish on which it was found to feed.

Diptera and fish appear to be major food items in the diet of the Sandusky Bay fish sampled. Oligochaetes and diatoms were also found to be important food items. This is not to imply that the phytoplankton and zooplankton are not utilized. These abundant forage items are utilized by other species of fish not sampled in this study, primarily the Gizzard shad.

Commericial Fishery

Sandusky Bay is highly productive in fish harvest. The average annual commercial catch from 1938-1974 is 2,545,952 pounds. Table 5 shows the catch by species for all available years during 1938-1974. The commercial catch is illustrated graphically in Figure 9. This figure illustrates the fluctuations

Table 5: Commercial Catch Record for Sandusky Bay* 1938 - 1974

	1938	1939	1948	1949	1950	1951	1952	1953	1954	1955
Shiners	3,716	6,697	—	—	—	—	—	—	—	—
Suckers	7,642	2,905	3,781	6,582	1,155	5,695	10,732	8,819	8,481	—
Carp	432,874	595,990	332,326	774,824	577,238	682,273	551,037	940,128	1,362,164	—
Goldfish	176,951	85,676	110,005	152,860	93,053	115,608	90,500	97,094	81,475	—
Catfish	55,916	32,231	166,057	327,924	275,397	441,130	439,227	392,615	447,320	—
Bullheads	10,787	18,299	37,109	35,209	6,491	6,644	1,469	2,212	11,411	—
Yellow perch	789	2,640	2,251	2,515	3,514	3,208	11,526	25,300	71,452	36,238
Sauger	16,453	3,545	13,962	9,606	10,350	5,179	6,173	5,337	1,046	411
Yellow pickerel	5,629	6,762	33,989	46,428	64,038	71,482	73,322	102,154	48,804	42,860
White bass	38,173	17,902	81,360	85,078	216,344	174,284	140,538	135,497	283,335	—
Freshwater drum	448,257	409,089	865	915,184	614,458	914,479	836,928	310,965	301,317	—
Blue pike	—	—	168	—	10	—	18,472	95	99	11
Northern pike	—	—	4	3,392	1,631	15	541	299	—	—
Gizzard shad	—	—	—	30,000	20,425	404	—	—	—	—
Mooneye	—	—	5,356	5,028	3,907	17,240	10,540	7,795	3,276	—
Buffalo	—	—	4,834	5,164	3,270	2,188	2,042	17,965	17,881	—
Bowfin	—	—	—	4,300	755	—	—	—	—	—
Sturgeon	—	—	449	—	5	—	35	315	49	—
Whitefish	—	—	406	42	40	6	219	278	316	—
Miscellaneous	—	—	—	—	—	—	170	1,972	323	—
Burbot	—	—	60	1,800	163	46	480	10	—	43,280
Grass Pike	—	—	—	—	—	—	—	—	749	—
Cisco	—	—	—	—	—	—	—	—	—	—
Smelt	—	—	—	—	—	—	—	—	—	—
Quillback	—	—	—	—	—	—	—	—	—	—
TOTAL	1,197,257	1,181,736	1,658,011	2,405,936	1,892,264	2,439,881	2,193,962	2,048,854	2,639,498	122,800

*In pounds.

Source: Edminster, 1940; Chapman, 1955; Ohio Department of Natural Resources, 1950-1974.

Table 5: Continued - Commercial Catch Record For Sandusky Bay*

	1968	1969	1970	1971	1972	1973	1974	Mean+
Shiners	—	—	—	—	—	—	—	—
Suckers	28,146	23,605	43,326	31,020	25,555	45,462	13,930	13,693
Carp	752,478	972,835	1,470,322	912,211	802,754	726,615	691,002	911,972
Goldfish	91,459	82,712	156,390	76,281	30,690	26,158	52,597	111,449
Catfish	291,298	276,529	176,898	193,513	149,319	78,753	80,206	275,037
Bullheads	8,983	22,249	17,164	21,657	9,185	9,576	11,192	25,385
Yellow perch	27,113	53,772	32,238	27,395	5,564	17,387	9,400	31,385
Sauger	—	—	—	—	—	—	—	2,005
Yellow pickerel	35,845	17,949	7,998	—	—	11,415	—	40,971
White bass	156,887	394,846	294,970	184,949	55,662	986,737	1,143,081	219,251
Freshwater drum	2,540,353	1,584,554	659,822	441,982	319,596	336,221	234,205	1,047,882
Blue pike	—	—	—	—	—	—	—	726
Northern pike	—	—	—	—	—	—	—	226
Gizzard shad	—	—	—	—	—	—	—	2,446
Mooneye	37	17	—	—	—	—	—	2,242
Buffalo	18,312	7,813	7,267	2,347	494	8,887	8,945	8,890
Bowfin	—	—	—	—	—	—	—	195
Sturgeon	—	—	—	—	—	—	—	40
Whitefish	186	—	—	—	—	—	—	380
Miscellaneous	269	440	2,350	—	—	—	—	1,107
Burbot	—	—	—	—	—	—	—	1,855
Grass pike	—	—	—	—	—	—	—	29
Cisco	—	—	—	—	—	—	—	40
Smelt	—	—	—	—	—	20	4,849	189
Quillback	—	—	—	—	1,144	11,460	13,807	1,016
TOTAL	4,116,366	3,437,321	2,868,745	1,981,360	1,399,963	2,258,691	2,263,222	

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*In pounds.
+The means were calculated using only the data from 1948-1974.

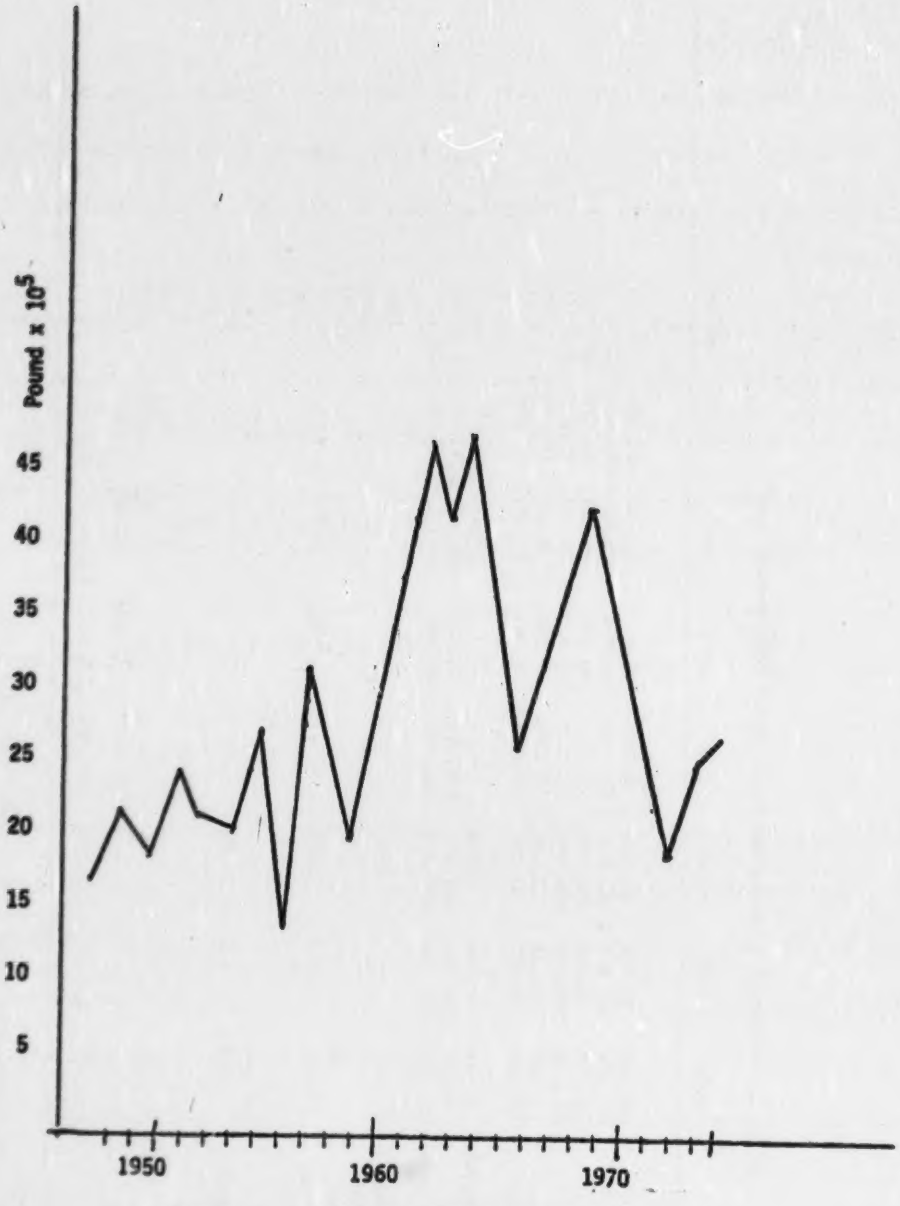

FIGURE 9. TOTAL COMMERCIAL CATCH OF FISH (1948-1974)

in the commercial harvest. The harvest is now higher than during the 1930's and 1940's. Although down from the late 1960's, the commercial catch is on another upward swing.

The commercial catch for 1973 and 1974 was 2,258,691 pounds and 2,263,222 pounds respectively. Rough fish comprised 51% of the catch in 1973 and 45% in 1974. Game fish comprised 49% of the catch in 1973 and 55% in 1974.

The important game species in 1973 and 1974 were White bass, Channel catfish, and Yellow perch. Figure 10 graphically illustrates the commercial catch of White bass. There are fluctuations in the catch record but the population appears to be relatively stable until 1972-1974 when a tremendous increase occurred, more than doubling the commercial catch.

The commercial catch of Channel catfish was lower in 1973-1974 than it has been since 1948 (figure 11). The Channel catfish appears to have prospered during the 1950's, then slowly declined through the 1960's and early 1970's.

The Yellow perch population, as reflected by the commercial catch records, has fluctuated dramatically (figure 12). The 1930's and 1940's show a low stable population increasing in the 1950's, proceeding to peak and drop roughly every three years from 1952 through 1974. The Yellow perch is an unstable population subject to large scale drops. The population appears to be under environmental stress with a brood stock not large enough to compensate for a bad year class.

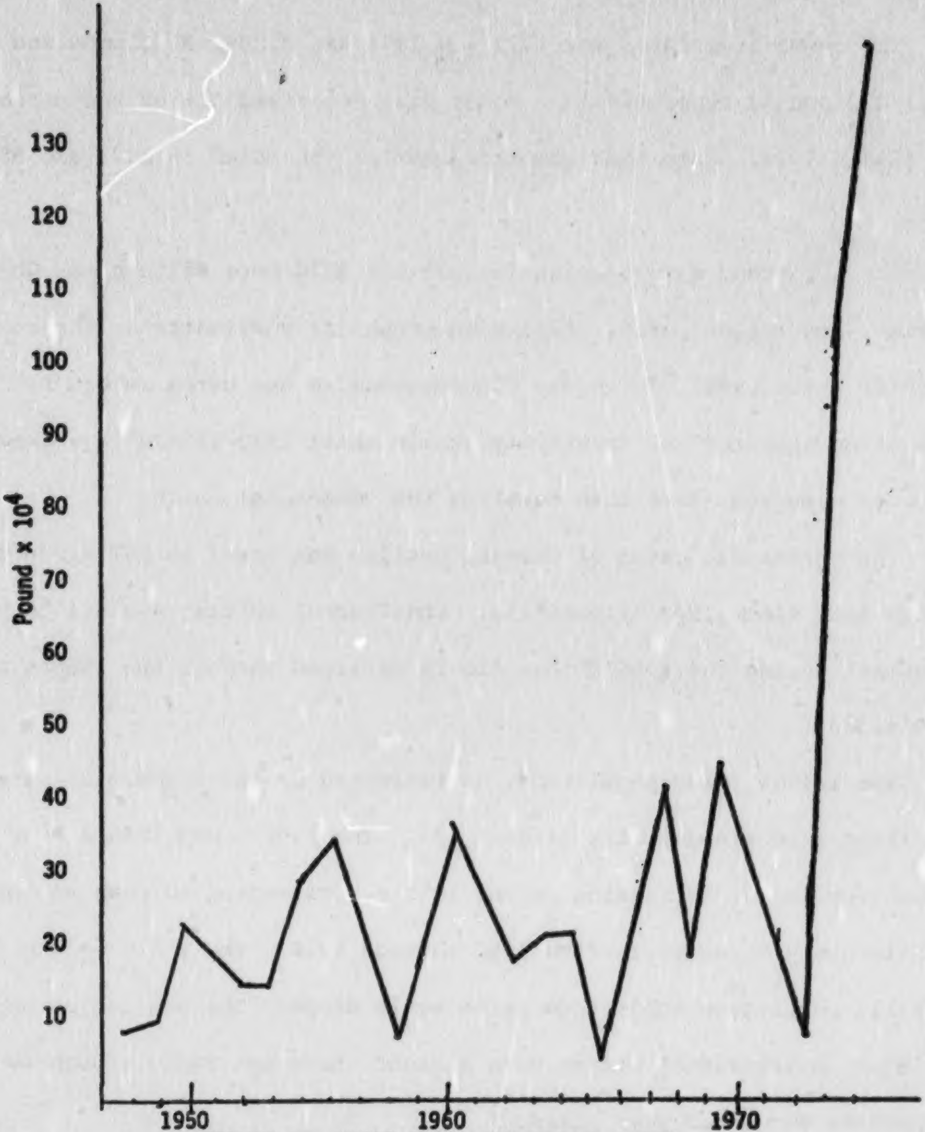

FIGURE 10. WHITE BASS– COMMERCIAL CATCH
(1948-1974)

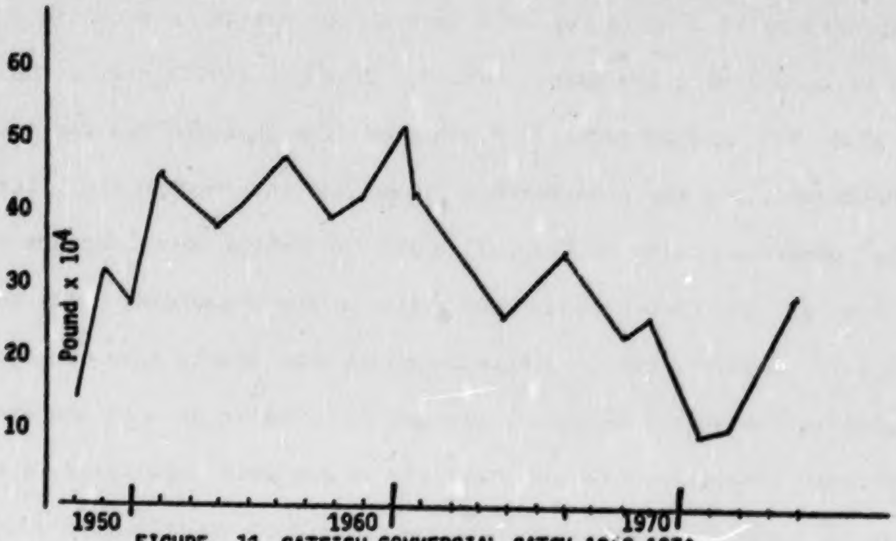

FIGURE 11. CATFISH-COMMERCIAL CATCH 1948-1974

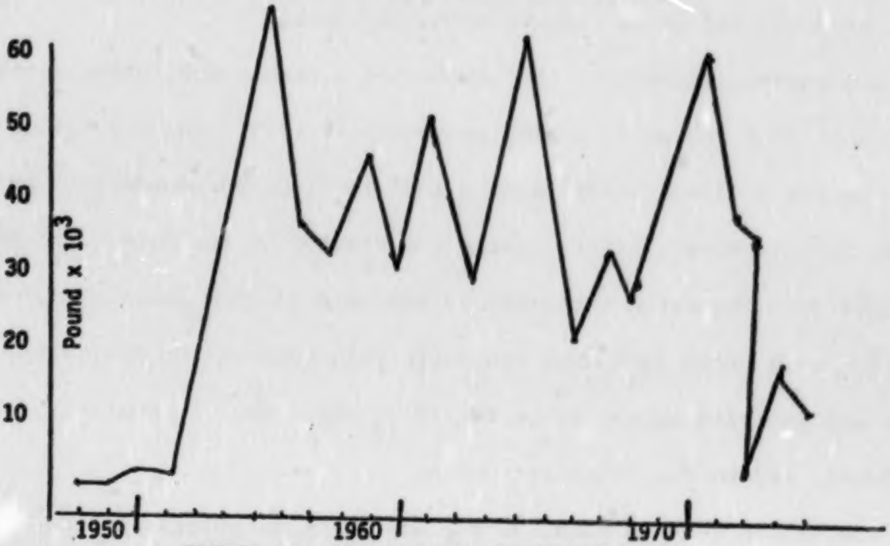

FIGURE 12. YELLOW PERCH-COMMERCIAL CATCH
(1948-1974)

The important rough species for 1973 and 1974 were: Freshwater drum, Carp, Sucker, and Goldfish. The Freshwater drum catch has fluctuated markedly (figure 13). This may represent a true change in the fish population or be due to a low market demand. Trautman (1957) states that during 1939-1949, the poundage of Freshwater drum captured was far greater than the demand, and the unmarketable excess was returned to the water.

The commercial catch of Carp, like the Freshwater drum, depends on market demand. The Carp has numerous peaks in its commercial catch record (figure 14). However, the Carp appears to be more stable than the Freshwater drum. The increases and decreases are not so dramatic as with the Freshwater drum, perhaps indicating greater stability in the carp population or market. Both the Carp and the Freshwater drum are consistent contributors to the commercial catch and do not appear to be declining.

The Goldfish (figure 15) has maintained a stable population until 1971 when it fell to a record low, hitting bottom in 1973. The 1974 catch was up. The population is again stabilizing around the 100,000 pounds/year mark.

The Suckers were a fairly stable contributor to the commercial catch until 1967 when the catch increased by two-fold (figure 16). The increasing trend continued until 1974 when the catch fell back to the 1967 level. The Suckers and Goldfish appear to be fairly stable. The fluctuations, which are evident, may be due to market demand.

A comparison between Sanduksy Bay and the Ohio waters of Lake Erie shows that Lake Erie contains 881,758 hectares while Sandusky Bay contains only 89 hectares (Chapman, 1955). If Sandusky Bay and the Ohio waters of

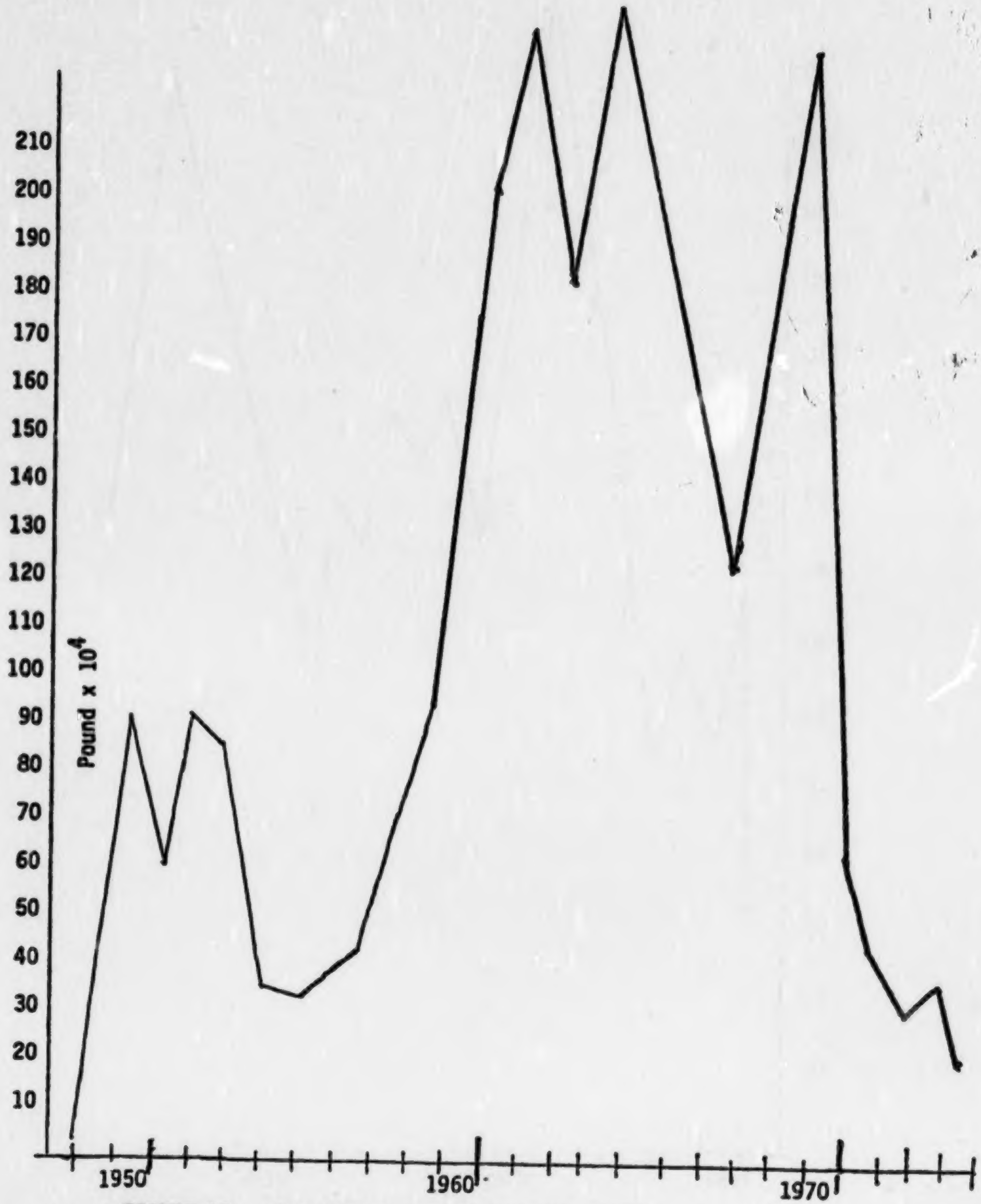

FIGURE 13. FRESHWATER DRUM-COMMERCIAL CATCH
(1948-1974)

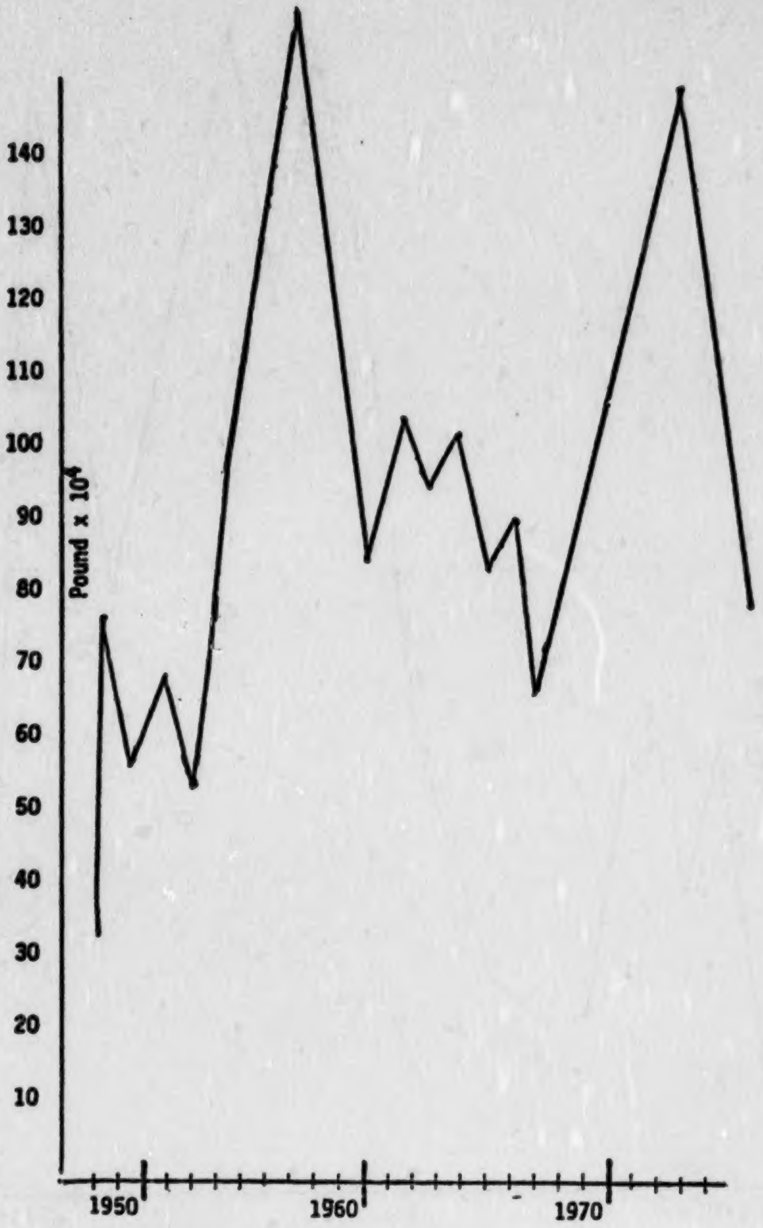

FIGURE 14. CARP-COMMERCIAL CATCH (1948-1974)

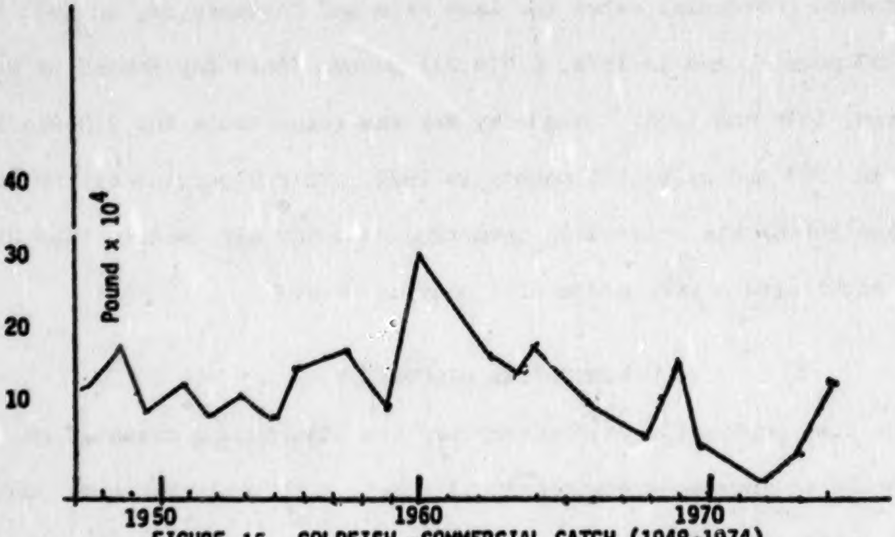

FIGURE 15. GOLDFISH - COMMERCIAL CATCH (1948-1974)

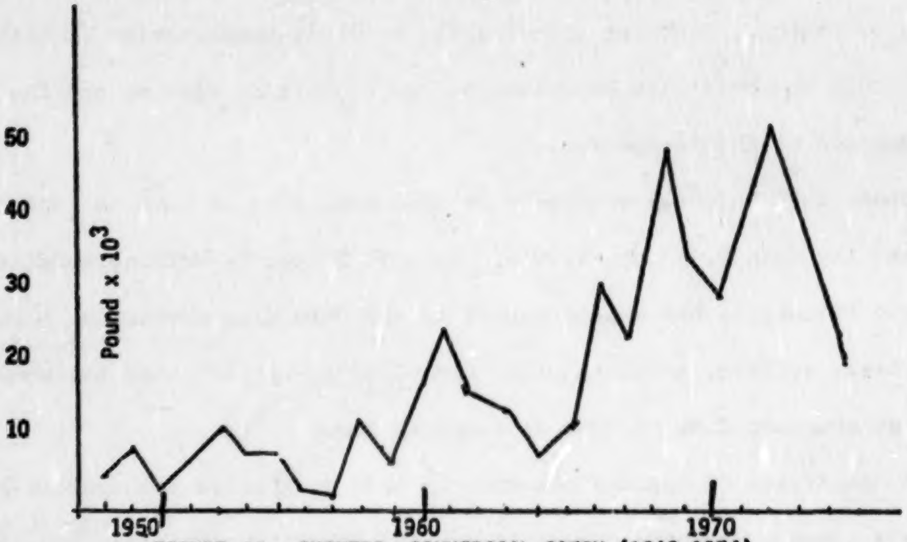

FIGURE 16. SUCKERS - COMMERCIAL CATCH (1948-1974)

Lake Erie were combined, 2% of the final figure would represent Sandusky Bay while the remaining 98% would represent the Ohio waters of Lake Erie. The combined commercial catch for Lake Erie and Sandusky Bay in 1973 was 7,429,857 pounds, and in 1974, 8,728,211 pounds (Ohio Department of Natural Resources, 1974 and 1975). Sandusky Bay was responsible for 2,258,691 pounds in 1973 and 2,263,222 pounds in 1974. Thirty percent of the 1973 catch and 26% of the 1974 catch came from Sandusky Bay, making that 2% of the total area a very productive body of water.

HISTORICAL DISCUSSION

The fish population of Sandusky Bay has undergone a dramatic change in response to increased environmental stress. Factors that have contributed to this environmental stress are: deforestation, plowing of virgin prairie, diking of marshes, ditching and draining of land, construction of mill dams and in 1910 the Ballville Dam, intensified commercial fishing and the introduction of exotic species.

These environmental changes were just beginning to have an impact on the Sandusky Bay fishery in the 1870's. In 1877 Klippart, writing about the 1830's Sandusky fishery in his annual report to the Ohio Fish Commission listed White bass, Walleye, Northern pike, Muskellunge, Catfish, and Blackbass as the most abundant fish species in Sandusky Bay.

A comparison of species abundant in 1830 to species abundant in 1940 and 1974 shows a dramatic change in species comprising the fish population in the last century and a half (table 6). From 1940 to 1974 the change is one of relative abundance.

Table 6: Comparison of fish species abundance

(Species listed in decreasing abundance)

1830*	1940+	1975**
White Bass	White crappie	Gizzard shad
Walleye	White bass	Yellow perch
Northern pike	Gizzard shad	White bass
Channel catfish	Carp and Goldfish	Carp and Goldfish
Largemouth bass	Bullheads	White crappie
Muskellunge	Freshwater drum	Bullheads
	Channel catfish	Freshwater drum
	Black crappie	Channel catfish
		Walleye

* Klippart, 1877
+ Edminster, 1940
** Present Study

The decline of the once-abundant Northern pike and Muskellunge was caused by several factors. The mill dams built during the early 1800's blocked the upstream migration. The draining and diking of marshes removed spawning habitat, and by 1900 the commercial fishing pressure on these two species (first to become commercially important) was intense. The increased turbidity and decreased aquatic vegetation furnished the final blow to the Northern pike and the Muskellunge (Trautman, 1957). The Muskellunge has become so severly depleted in Sandusky Bay and Lake Erie that it is considered to be an endangered species by The Ohio Division of Wildlife.

Both the Smallmouth and Largemouth bass were commercially important species in 1830, and were very abundant until the 1900's. In 1902, commercial fishing for these species was prohibited (Trautman, 1957). The Largemouth and Smallmouth blackbass are now common and uncommon respectively (Willis, 1974).

Trautman lists turbidity, dams, and silting over of firm bottoms as the major reasons for the decline of the Walleye. The Walleye was still entering the commercial catch in the 1930's, in small numbers. The catch increased in the early 1950's and has declined since then. The Walleye now provides a basis for an intense sport fishery. Edminster (1940) and Chapman (1956) found that the Walleye entered the bay in large numbers in the spring, but did not remain there long. The 1972-1974 information indicates a small number of Walleye was present in the bay. It is felt that this information represents a small resident population or stragglers and that the large spawning run was missed.

The White bass has gone from the most abundant species in the bay to a lower position on the abundant species list. The White bass is a highly migratory species preferring clear water, firm bottoms, an abundance of small fish and a depth of less than 30 feet (Trautman, 1957). The depth requirement is obviously met in Sandusky Bay and the abundance of small fish is fairly certain. However, the clear water and firm bottoms are conspicuously absent. Despite this combination of favorable and unfavorable factors, the White bass appears to be holding stable and has increased in pounds taken commercially over the last forty years. Young-of-the-year White bass were taken in Sandusky Bay in June, July, and August of 1974. The June trawls yielded 110 young per five minute tow, the largest catch.

The Channel catfish prefers clean bottoms, deeper or larger waters, but will tolerate silt, providing the rate of deposition is low (Trautman, 1957). It does not require aquatic vegetation. Apparently its tolerance of silt and its lack of dependency on aquatic vegetation have allowed it to continue and maintain the population in Sandusky Bay. Edminster (1940) and Chapman (1955) found the catfish to be a seasonal member of the community structure, present in the spring and returning to the lake in the summer or fall.

The White crappie is presumed to have been common before the 1900's. As the Walleye, Northern pike and Muskellunge decreased, the White crappie increased. The White crappie is tolerant to a wide variety of habitats, especially turbid water. Turbid conditions in the bay favor the White crappie over the Black crappie. This is evident in Edminster's study (1940) amd the present study. Black crappies were caught on a ratio of 1 to 100 and 1 to 10 respectively. The White crappie fell from comprising 72% of the 1940 catch to 8.4% of the 1972-1974 catch. This may be due to a decline in the White crappie population, an increase in the other more abundant species (Gizzard shad and Yellow perch) or to differences in sampling technique.

The Gizzard shad was not mentioned by either Klippart (1877) or Edminster (1940). Trautman (1957) indicated that the Gizzard shad was probably present before the 1900's. By 1974 the Gizzard shad had become abundant. The Gizzard shad favors turbid waters where there is an abundance of phytoplankton. Sandusky Bay satisfies both of these habitat preferences. Phytoplankton is greatest in July with an average value of 623,287 organisms per liter. The Gizzard shad has not been taken commercially since 1966 and is considered to be an under utilized resource. Young-of-the-year Gizzard shad were taken in large numbers in 1974. The greatest catch was in May when 3,300 individuals were caught per five minute tow.

The Carp was introduced into Lake Erie waters in 1879. The Goldfish was introduced in 1888. The Carp and Goldfish were listed by Edminster (1940) as being permanent residents of the Sandusky Bay fish community, seldom migrating out. The Carp is tolerant of pollution and various types of bottoms. The Goldfish is more dependent on aquatic vegetation and is less tolerant of pollution and turbidity. Both species have increased rapidly and are now abundant. Young-of-the-year Goldfish were caught in June of 1974 and comprised 1% of the total ichthyoplankton catch (less than one fish per five-minute tow).

The Yellow perch prefers clear water and rooted vegetation. The Yellow perch normally decreases with increased turbidity. Yet it has remained abundant in Sandusky Bay. The Yellow perch is seasonal, moving in with spring and out during the summer and back in the fall to be a primary contributor to the winter fishery (Chapman, 1956). Young of the year Yellow perch were caught in Sandusky Bay in May, 30 individuals per five-minute tow.

The Freshwater drum was abundant before 1860 and remained abundant through 1950 according to Trautman (1957). Edminster (1940) supports Trautman's statement and the 1972-1974 information indicates Freshwater drum is still abundant. The Freshwater drum can tolerate turbid water and is capable of adjusting its food habits to available forage (the Freshwater drum shifted from snails and molluscs to fish, insects and crayfish). The Freshwater drum is so abundant in Sandusky Bay that the 1970 Ohio Revised Code contains the following law (1533.56): "Carp and sheepshead may be taken from Sandusky Bay to improve the habitat for other fish and provide a better balance of fish in Sandusky Bay; Carp and Sheepshead of any length may be taken, caught, possessed, bought and sold from within Sandusky Bay. Such fish may be taken and caught only in the manner provided by law....."

Young of the year Freshwater drum were taken in icthyoplankton trawls in June and May with the greater number being taken in May (10 and 478 young respectively). In 1956,Chapman found the Freshwater drum comprised 6.7% of the hatch of the year.

Bullheads were not mentioned in Klippart's (1877) report but Trautman (1957) indicates that all three species were abundant before 1900. Edminster's (1940) information lumped the bullheads together into one count. However, he stated that Brown and Black bullheads occurred in a ratio of 2:1. In the present study Brown bullheads were found to the virtual exclusion of the Black bullheads. Yellow bullheads were not mentioned in Edminster's work and were not taken in the present study. Bullheads as a group are often referred to as being tolerant of adverse conditions (Lagler, 1956). Both the Brown and the Black bullhead are currently considered to be common (Willis, 1974) but the Yellow bullhead is decreasing. The Yellow bullhead is the least tolerant of turbid conditions and was already decreasing in 1957 (Trautman). The Black bullhead is more tolerant than the Brown bullhead, yet less than 1% of the bullheads caught were Black bullheads. Trautman (1975) discussed the possibility of the "Brown bullheads" really being intergrades of Brown and Black bullhead crosses. Trautman indicated that the Brown and Black bullhead hybrid is fertile.

Status and Trend of Sandusky Bay Fish

The status and trend of the 24 species captured in the present study is given in Table 7. The table indicates that 10 species are abundant. Of these 10, three are increasing, seven are stable, and none is decreasing. Ten species are common; of these none is increasing, four are stable, and six are decreasing. Four uncommon species were captured, two are stable and two are decreasing. One rare species, the Northern pike, was captured; it is decreasing.

A total of 75 species has been reported for Sandusky Bay (Willis, 1974). The 75 reported species are given in Table 8. They are listed according to their abundance. The population trend, where known, is given. The table

TABLE 7: Status and trend of Sandusky Bay fish

SCIENTIFIC NAME	COMMON NAME	STATUS	TREND	FRY
Lepisosteidae				
Lepisosteus osseus	Longnose gar	Common	Decreasing	
Amiidae				
Amia calva	Bowfin	Uncommon	Decreasing	
Clupeidae				
Alosa pseudoharengus	Alewife	Common		
Dorosoma cepedianum	Gizzard shad	Abundant	Increasing	X
Esocidae				
Esox lucuis	Northern pike	Rare		
Cyprinidae				
Carassius auratus	Goldfish	Abundant		X
Cyprinus carpio	Carp	Abundant		
Notropis atherinoides	Emerald shiner	Abundant		X
Notropis hudsonius	Spottail shiner	Abundant		
Catostomidae				
Carpiodes cyprinus	Quillback	Uncommon	Decreasing	
Catostomus commersoni	White sucker	Common		
Moxostoma	Redhorse	Common		
Ictaluridae				
Ictalurus nebulosus	Brown bullhead	Common	Decreasing	
Ictalurus melas	Black bullhead	Common		
Ictalurus punctatus	Channel catfish	Abundant		
Percopsidae				
Percopsis omiscomaycus	Trout-perch	Common	Decreasing	
Percichthyidae				
Morone chrysops	White bass	Abundant	Increasing	X
Centrarchidae				
Micropterus dolomieui	Smallmouth bass	Uncommon		X
Micropterus salmoides	Largemouth bass	Common		
Pomoxis annularis	White crappie	Abundant		
Pomoxis nigromaculatus	Black crappie	Common	Decreasing	
Percidae				
Perca flavescens	Yellow Perch	Abundant		X
Stisostedion v. vitreum	Walleye	Uncommon		
Sciaenidae	Fresh			
Aplodinotus grunniens	Freshwater drum	Abundant		X

TABLE 8: Continued

UNCOMMON		POPULATION TREND
Common shiner	*Notropis cornutus*	
Sand shiner	*Notropis stramineus*	
Fathead minnow	*Pimephales promelas*	Increasing
Quillback	*Carpiodes cyprinus*	Decreasihg
Northern hog sucker	*Hypentelium nigricans*	
Bigmouth buffalo	*Ictiobus cyprinellus*	Decreasing
Spotted sucker	*Minytrema melanops*	Decreasing
Golden redhorse	*Moxostoma erythrurum*	Decreasing
Tadpole madtom	*Noturus gyrinus*	Decreasing
Brindled madtom	*Noturus miurus*	Decreasing
Banded killifish	*Fundulus diaphanis*	Decreasing
Smallmouth bass	*Micropterus dolomieui*	
Greenside darter	*Etheostoma blennioides*	
Johnny darter	*Etheostoma nigrum*	Decreasing
Walleye	*Stizostedion v. vitreum*	Increasing
RARE		
Silver lamprey	*Ichthyomyzon unicuspis*	Decreasing
Lake sturgeon	*Acipenser fulvescens*	Decreasing
Spotted gar	*Lepisosteus oculatus*	Decreasing
Mooneye	*Hiodon tergisus*	Decreasing
Lake whitefish	*Coregonus clupeaformis*	Decreasing
Northern pike	*Esox lucius*	Decreasing
Muskellunge	*Esox masquinongy*	Decreasing
Silver chub	*Hybopsis storeriana*	Decreasing
Blackchin shiner	*Notropis heterodon*	Decreasing
Blacknose shiner	*Notropis heterolepis*	Decreasing
Lake chubsucker	*Erimyzon sucetta*	Decreasing
Silver redhorse	*Moxostoma anisurum*	Decreasing
Burbot	*Lota lota*	
Longear sunfish	*Lepomis megalotis*	
Warmouth sunfish	*Lepomis gulosus*	
Iowa darter	*Etheostoma exile*	Decreasing
Channel darter	*Percina copelandi*	
Blackside darter	*Percina maculata*	
Sauger	*Stizostedion canadense*	Decreasing
Blue walleye	*Stizostedion vitreum glaucum*	Decreasing

TABLE 8: Composite list of species present in Sandusky Bay

ABUNDANT		**POPULATION TREND**
Gizzard shad	*Dorosoma cepedianum*	Increasing
Goldfish	*Carassius auratus*	
Carp	*Cyprinus carpio*	
Ermerald shiner	*Notropis atherinoides*	
Spottail shiner	*Notropis hudsonius*	Increasing
Spotfin shiner	*Notropis spilopterus*	Increasing
Bluntnose minnow	*Pimephales notatus*	
Channel catfish	*Ictalurus punctatus*	
White bass	*Morone chrysops*	Increasing
White crappie	*Pomoxis annularis*	
Yellow perch	*Perca flavescens*	
Freshwater drum	*Aplodinotus grunniens*	
COMMON		
Longnose gar	*Lepisosteus osseus*	Decreasing
Alewife	*Alosa pseudoharengus*	
Rainbow smelt	*Osmerus mordax*	Decreasing
Golden shiner	*Notemigonus crysoleucas*	Decreasing
Mimic shiner	*Notropis volucellus*	Decreasing
White sucker	*Catostomus commersoni*	
Shorthead redhorse	*Moxostoma macrolepidotum*	Decreasing
Black bullhead	*Ictalurus melas*	
Yellow bullhead	*Ictalurus natalis*	Decreasing
Brown bullhead	*Ictalurus nebulosus*	
Stonecat	*Noturus flavus*	Decreasing
Trout-perch	*Percopsis omiscomaycus*	Decreasing
Brook silverside	*Labidesthes sicculus*	Decreasing
Rock bass	*Ambloplites rupestris*	
Green sunfish	*Lepomis cyanellus*	
Pumpkinseed	*Lepomis gibbosus*	
Orangespotted sunfish	*Lepomis humilis*	Increasing
Bluegill	*Lepomis macrochirus*	
Largemouth bass	*Micropterus salmoides*	
Black crappie	*Pomoxis nigromaculatus*	Decreasing
Logperch	*Percina caprodes*	Decreasing
UNCOMMON		
Sea lamprey	*Petromyzon marinus*	
Bowfin	*Amia calva*	Decreasing
Coho salmon	*Onchorhynchus kisutch*	
Chinook Salmon	*Onchorhynchus tshawytsha*	
Central mudminnow	*Umbra limi*	Decreasing
Grass pickerel	*Esox americanus vermiculatus*	Decreasing
Stoneroller	*Campostoma anomalum*	

is based on a search of the records of the Ohio State University Museum of Zoology and an examination of Trautman's Fishes of Ohio (1957) distribution maps by Charles F. Willis. The table was updated for this study incorporating the 1972-1974 catch records. According to Trautman (1975), eight species have been virtually extirpated from Sandusky Bay. These are: Sturgeon, Muskellunge, Lake chubsucker, Blackchin shiner, Blacknose shiner, Channel darter, Iowa darter, and Longear sunfish.

The reasons for the decline of the Muskellunge have already been discussed. The Sturgeon declined for similar reasons. The building of mill dams in the 1800's and, on the Sandusky River, the Ballville Dam in the early 1900's blocked the Sturgeon spawning runs. The Sturgeon was also a nuisance to the commercial fisherman. They became tangled in the nets, thrashing and tearing the nets. For this reason the Sturgeon was often destroyed. The Sturgeon does not reproduce until it is about 20 years old; once the population was down there was little chance of restoring it for a long period of time.

Six of the remaining seven species appear to have been extirpated by similar causes. These six are all reported to be intolerant of turbidity and/or require aquatic vegetation (Trautman, 1957). The Channel darter is the exception to this statement and the reason for its decline is unknown.

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ABSTRACT

ZOOPLANKTON POPULATIONS OF SANDUSKY BAY, LAKE ERIE

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Monthly analyses of zooplankton populations during 1974 from Sandusky Bay, Lake Erie, show a predominance of forms characterizing the communities of eutrophic waters. Species *Brachionus* and *Polyartha* were the dominant rotifers during the spring, whereas *Pompholyx sulcata* was dominant during the summer. *Keratella cochlearis* and *K. quadrata* remained abundant from April to October. *Cyclops vernalis*, the principle cyclopoid copepod, reached maximums in May-June, while the calanoids were represented almost entirely by *Diaptomus siciloides*. Development of cladocerans was greatest during the months of June and July with *Daphnia retrocurva, Eubosmina coregoni, Bosmina longirostris*, and *Chydorus sphaericus* common. With total numbers of organisms ranging from a maximum of 1167 ind/l on 30 May to winter minimums of 25 ind/l, abundance of zooplankton in the bay was considerably greater than reported for Lake Erie proper. Development of zooplankton populations occurred along a gradient with maximums at stations near the mouth of the Sandusky River, the furthest distance from open water, and near areas of lowest phytoplankton density. The great and almost exclusive abundance and distribution of zooplankton associated with eutrophic conditions is evidence of high nutrient levels; shallow, warm water; turbidity due to sediment; limited circulation between the bay and open lake; and possible predation by gizzard shad.

ABSTRACT

USE OF MERCURY POLLUTION IN SANDUSKY BAY SEDIMENTS TO DETERMINE SEDIMENTATION RATES

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Surface sediments in cores from Sandusky Bay are enriched in mercury by a factor of 10 to 20 times above background levels. The background levels were established using sediment samples from Tymochtee and Broken Sword Creeks. These control samples had an average level of 0.031 ppm Hg (dry weight) in the less than 60 mesh fraction. In contrast, the surface sediments in 35 cores from Sandusky Bay ranged from 0.10 to 0.80 ppm Hg (dry weight).

Average sedimentation rates, calculated for the Sandusky Bay cores, ranged from 0.3 to 2.0 cm/year. The western bay had the highest rates of sediment deposition (up to 2.0 cm/yr) while deposition in the eastern bay generally was less than 1.3 cm/yr. The sedimentation rates were calculated by setting the depth at which the mercury concentration departed from the background level equivalent to 1941. This date represents an estimate of the time pollutant mercury began to be introduced into the Sandusky River-Sandusky Bay system. Analyses of sediment samples from 13 stations on the Sandusky River show that the sediments are enriched in mercury down stream of Bucyrus, Ohio.

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USE OF HEAVY METAL POLLUTION IN SANDUSKY BAY SEDIMENTS TO DETERMINE SEDIMENTATION RATES

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INTRODUCTION

Mercury, chromium, and nickel were determined in sediment cores from Sandusky Bay and the fine fraction of sediment samples from the Sandusky River, Broken Sword Creek and Tymochtee Creek. Walters et al. (1974) previously reported the results for mercury in one core from Sandusky Bay which was collected in 1971. Skoch and Sikes (1973) determined the mercury levels in Sandusky Bay sediments at two sites sampled monthly (February through November, 1972). These early studies suggested that the sediments of Sandusky Bay contained a low level of mercury pollution, averaging 0.6 ppm Hg dry weight.

The objectives of the present study were to: (1) confirm the pollution nature of Sandusky Bay sediments, (2) define a possible source area for the mercury pollution, and (3) estimate recent average sedimentation rates using the mercury pollution method of Wolery and Walters (1974).

METHODS

Sediment core samples were collected at 34 stations in Sandusky Bay in cooperation with L. L. Bradich of the Lake Erie Section, Ohio Division of Geological Survey. The coring was done in late September 1972 using the R/V GS-1.

These cores were sectioned into the following intervals measured from the sediment-water interface: 0-16 cm divided into 2 cm intervals; 16-40 cm divided into 4 cm intervals; 40-bottom of core divided into 10 cm intervals. These core intervals were homogenized and preserved frozen until they were analyzed for mercury, chromium, and nickel. Figure 1 is a sample location map for these cores. The sampling stations were located in both the west bay (22) and east bay (12).

Stream sediments from 26 stations on the Sandusky River, Tymochtee Creek and Broken Sword Creek, shown in Figure 2, were collected in January and February 1975 by students of the Department of Biological Sciences at Bowling Green State University. Twenty-three of these samples were collected at the same locations used by Stevenson and Pryfogle (1975), Bankieris and Barker (1975), and Prater et al. (1975). Three additional samples were collected in or near Bucyrus, Ohio.

These bottom sediment grab samples were wet sieved using standard stainless steel sieves and double distilled water. The fraction less than 250 microns was allowed to settle so that the excess water could be poured off before heavy metal analyses. Only the fine fraction was analyzed for heavy metals, because it was similar in particle size to the Sandusky Bay sediments.

Mercury, chromium and nickel were then determined by the standard atomic absorption methods of EPA (1974) and are reported as ppm dry weight. The cold vapor atomic absorption analysis procedure was used for mercury after digestion with sulfuric and nitric acids, potassium permanganate, and potassium persulfate. The chromium and nickel analyses were performed using

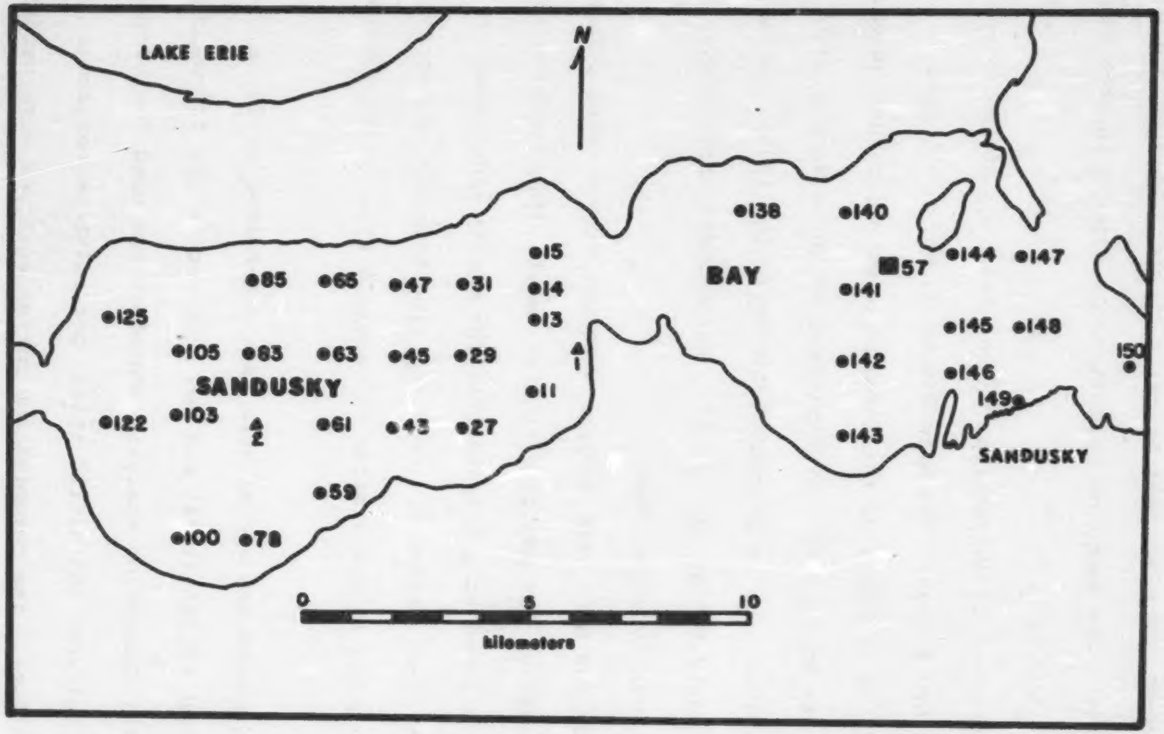
LAKE ERIE
N
SANDUSKY
BAY
SANDUSKY
125
105
83
63
45
29
122
103
2
61
43
27
85
65
47
31
15
14
13
1
11
59
100
78
138
140
57
141
142
143
144
147
145
148
146
149
150
0
5
10
kilometers

Figure 1. Sample location map of Sandusky Bay showing cores collected September 1972 (●) using the R/V GS-1 and those reported by Walters et al. (1974) (■) and Skoch and Sikes (1973) (▲).

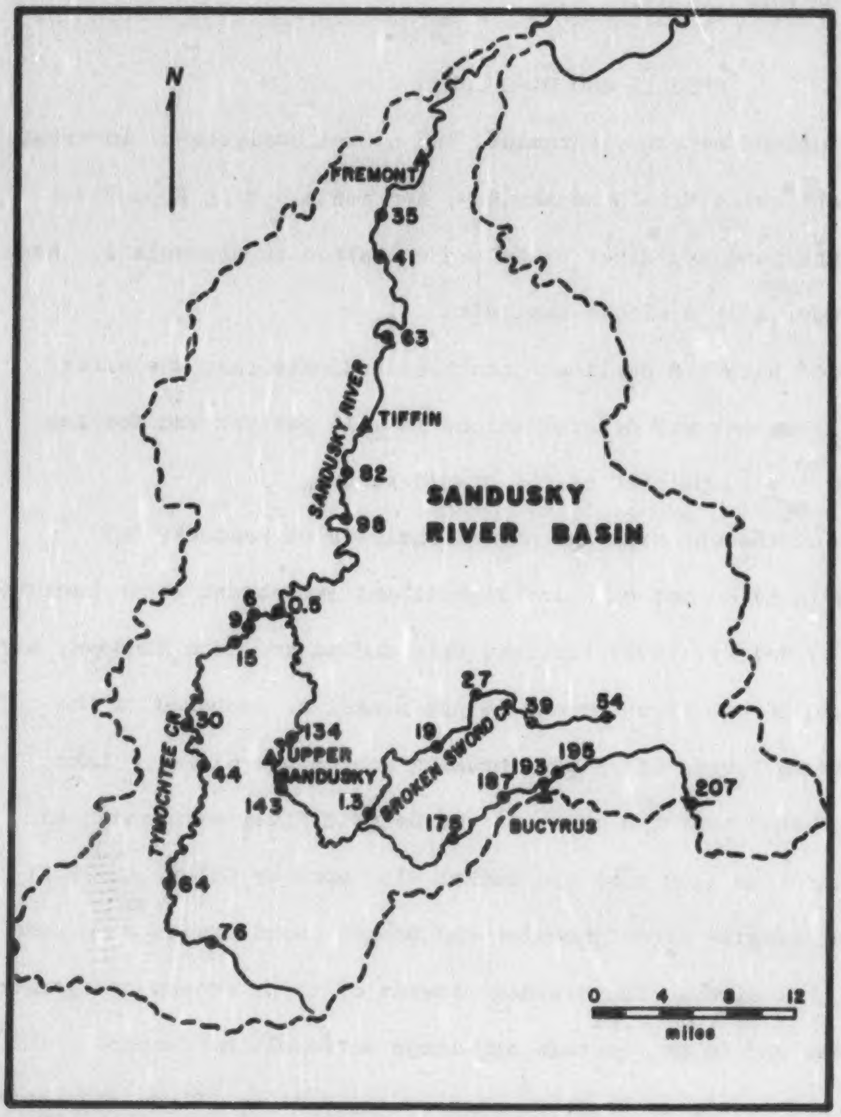
N
FREMONT
35
41
63
SANDUSKY RIVER
TIFFIN
82
98
SANDUSKY RIVER BASIN
6
0.5
9
15
30
TYMOCHTEE CR.
134
UPPER SANDUSKY
143
44
1.3
19
27
39
54
BROKEN SWORD CR.
195
193
187
175
BUCYRUS
207
64
76
0 4 8 12
miles

Figure 2. Sample location map for stream sediment samples from the Sandusky River, Tymochtee Creek, and Broken Sword Creek. The station numbers represent the distance in kilometers from the respective river or creek mouths.

standard flame atomic absorption procedures after extraction of a dried sample with hydrochloric acid and hydroxylamine hydrochloride according to the procedure of Wolery (1973).

RESULTS AND DISCUSSION

The results of the mercury, chromium, and nickel analyses of intervals within the sediment cores from Sandusky Bay, are contained in Appendix 1. The results for the Sandusky River Basin are contained in Appendix 2. Each of these values represent a single analysis.

The results of selected duplicate analyses indicate that the error associated with these mercury determinations is ± 15 percent and for the chromium and nickel ± 10 percent of the stated values.

The results of the chromium and nickel analyses of Sandusky Bay sediments (Appendix 1) do not show any significant enrichment above background levels reported by Wolery (1973) for Lake Erie sediments. The Sandusky Bay sediments averaged 24 ppm chromium and 40 ppm nickel as compared to the Lake Erie background levels of 18 ppm chromium and 45 ppm nickel. Lake Erie sediments located near the mouth of the Detroit River were shown to be enriched in chromium (160 ppm) and nickel (150 ppm) by Wolery (1973).

The sediment samples from Tymochtee and Broken Sword Creeks were used as controls for this study. The drainage basins of these creeks are primarily agricultural areas and do not contain any large metropolitan centers. The chromium and nickel levels in these samples averaged 13 to 25 ppm respectively and were not considered significantly different from the analyses of the bay sediments.

The mercury level for Tymochtee Creek, shown in figure 3, ranges between 0.02 and 0.04 ppm (dry weight). This level of mercury concentration is lower than the general background level reported by Walters et al. (1974) for western Lake Erie sediments but is in agreement with that of Wolery (1973) for central basin Lake Erie sediments. No significant variation was observed with distance from the mouth of the stream.

The mercury level in the Broken Sword Creek sediments (figure 4) was slightly higher than that in Tymochtee Creek. The Broken Sword sediments ranged between 0.02 ppm Hg and 0.05 ppm Hg. Again, no significant variation was observed in the mercury level as a function of distance from the mouth.

The average value for all of the Tymochtee and Broken Sword Creek samples was 0.031 ppm Hg (dry weight). This value represents the natural background level of mercury to be expected in the Sandusky Bay sediments. Similar values were observed at depth in sediment cores from Lake Erie (Walters et al., 1974; and Wolery, 1973). Kemp et al. (1975) found an average mercury concentration of 0.045 ppm for glacial till samples eroding from the bluffs along the north shore of the central basin of Lake Erie. These till samples should be similar to the surficial debris being transported into Sandusky Bay by the Sandusky River and its tributaries.

All 13 samples of Sandusky River sediment had mercury concentrations

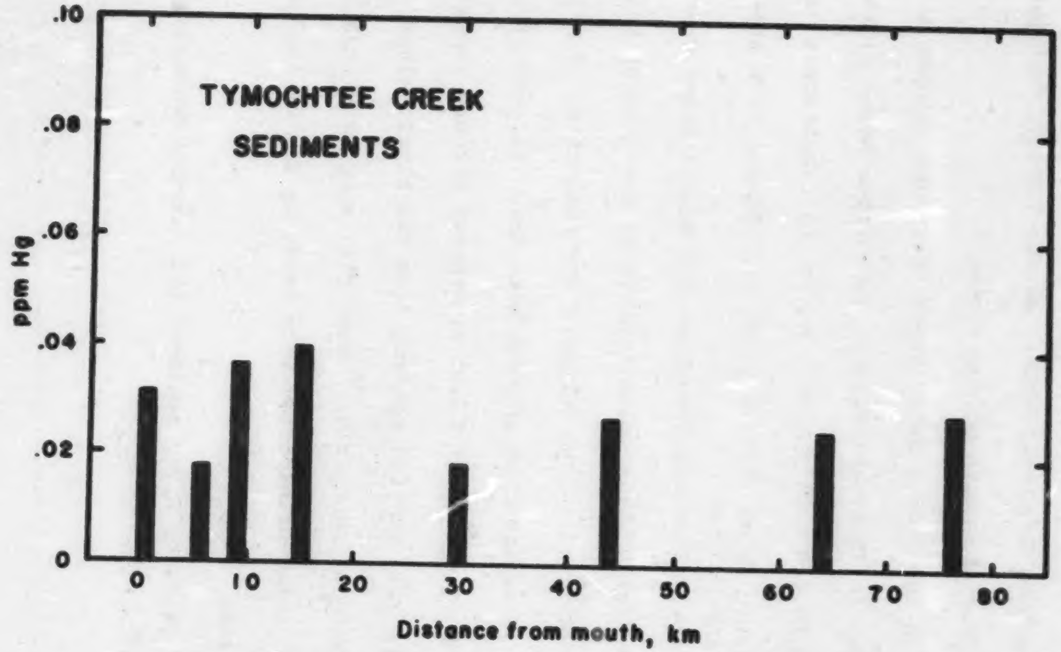

Figure 3. Mercury concentration in the less than 250 micron fraction of Tymochtee Creek sediments collected February 1975.

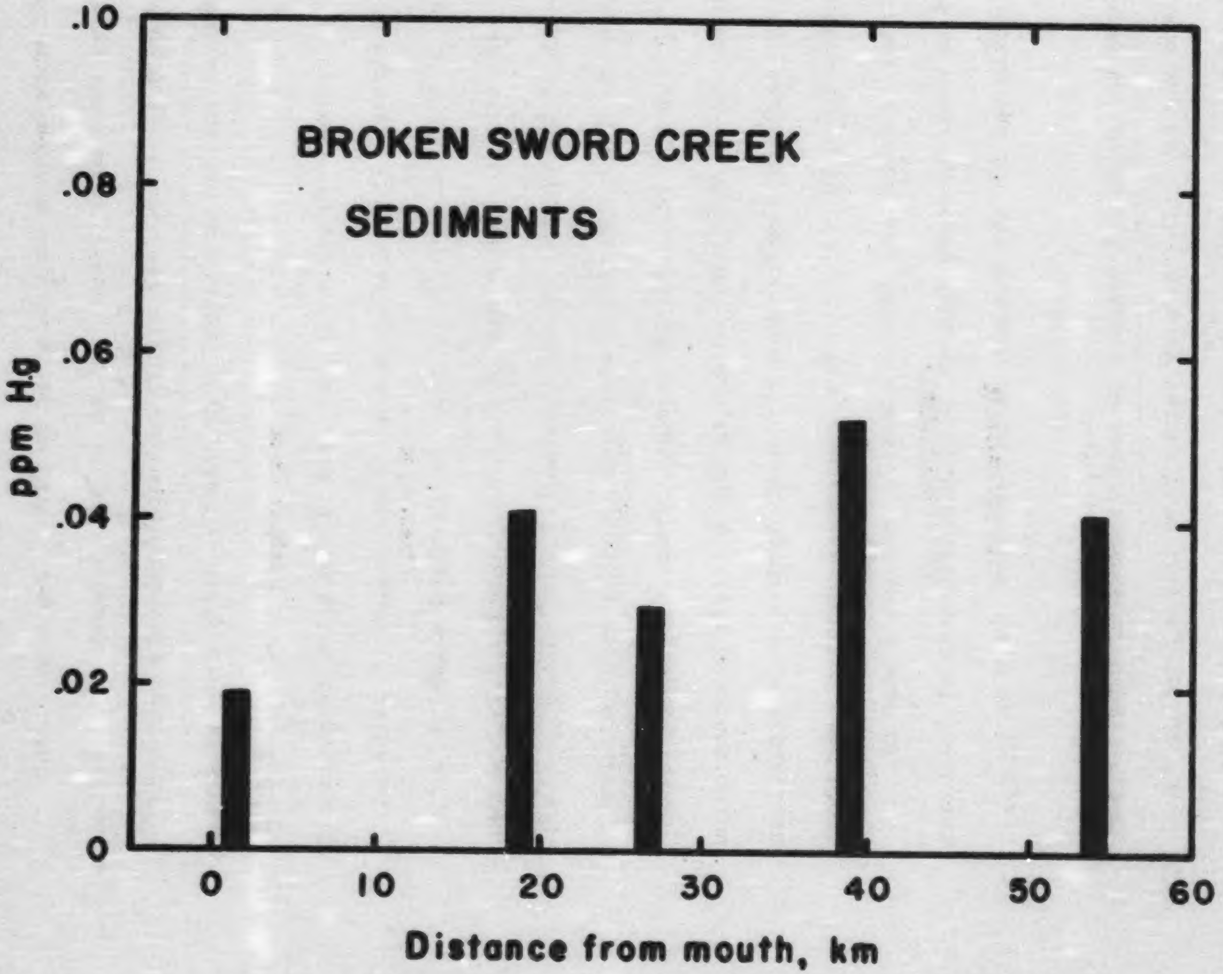

Figure 4. Mercury concentration in the less than 250 micron fraction of Broken Sword Creek sediments collected February 1975.

greater than the background value of 0.031 ppm established by the control samples. The highest levels (0.7 ppm) were observed down stream of the Bucyrus Sewage Treatment Plant. Moderately high levels of mercury were found in the sediments between Crestline and Bucyrus. Two significant features concerning the mercury concentration in the Sandusky River sediments can be seen in Figure 5. First, the highly polluted sediments were only observed near Bucyrus and did not extend down stream. These samples were collected on January 18 and February 15. This was during a period of very high water flow which tends to place the bed load of the River in suspension and flush it down stream. Furthermore, a significant amount of additional sediment is input to the drainage system from the farmland which has a dilution effect down stream. The second feature is pointed out by the two samples down stream of the Bucyrus Sewage Treatment Plant. Although these samples were collected almost one month apart, the mercury level observed was very constant, 0.69 ppm vs. 0.71 ppm mercury. Thus, the major pollution source is one of persistent nature, having a fairly constant output rate. Although the sediment samples down stream of Bucyrus show significant mercury levels, they are only one tenth the high levels observed near the mouth of the Detroit River in Lake Erie. Likewise, the total mass of mercury involved is small in comparison to the 228 metric tons of pollution mercury we have estimated for the western basin sediments (Walters et al., 1974).

Figure 6 shows the pollutant-mercury concentration-depth profiles for two cores from Sandusky Bay. The mercury values have been corrected for background by subtracting the average control value (0.031 ppm) from the

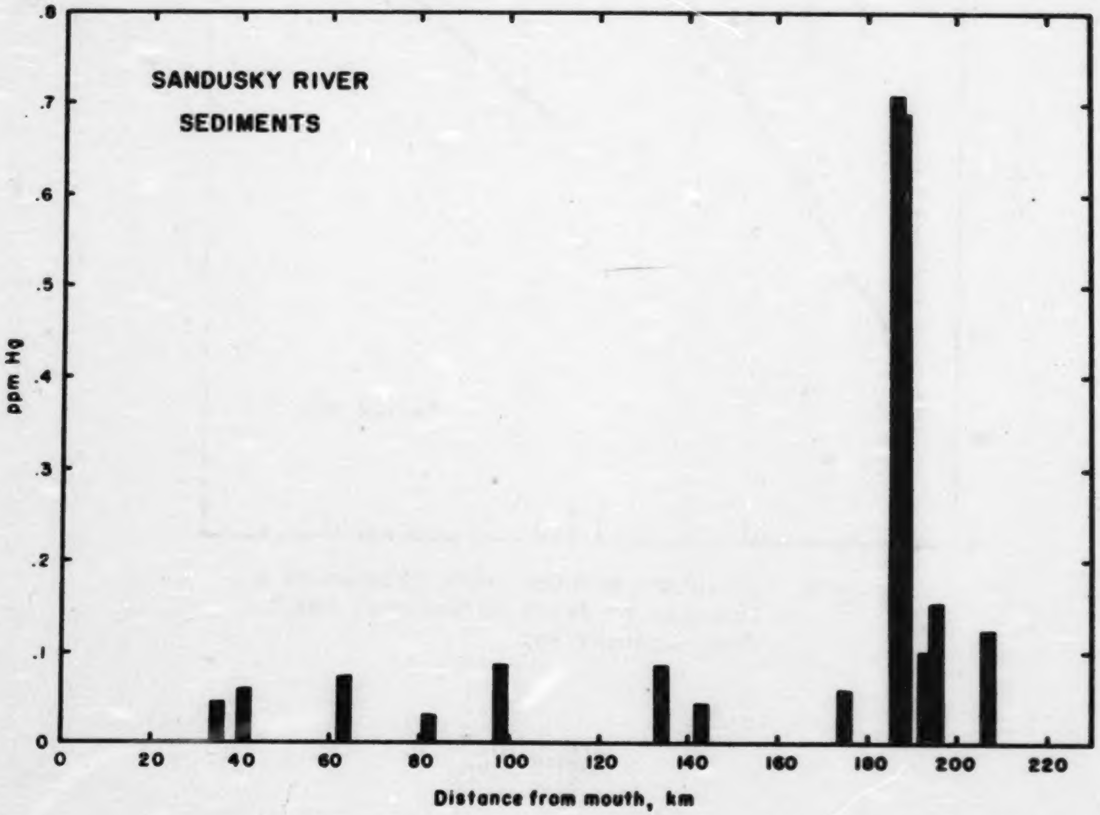

Figure 5. Mercury concentration in the less than 250 micron fraction of Sandusky River sediments collected January and February 1975.

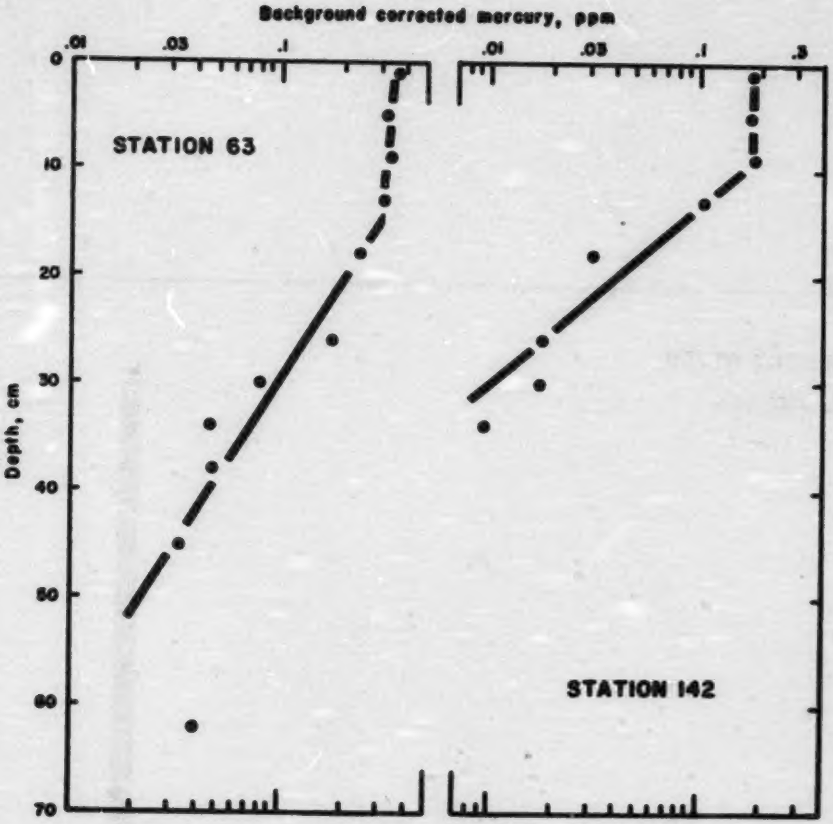

Figure 6. Pollutant mercury concentration as a function of depth in sediment cores from Sandusky Bay.

observed value. All of the Sandusky Bay cores had a concentration depth profile similar to these shown for station 63 from the west bay and 142 from the east bay. This profile shape is different from that reported by Walters et al. (1974) for the western basin of Lake Erie. The relatively constant value near the surface that begins to decrease at an exponential rate is similar in form to the distribution of cesium in Lake Michigan cores reported by Robbins and Edgington (1975). They attributed the constant zone at the surface to mixing of the sediments by organisms (bioturbation). Possibly some type of either mechanical or biological mixing process is operating in Sandusky Bay. Lindsay and Herdendorf (1975) reported populations as high as 18,000 benthic organisms/m^2 in Sandusky Bay. The observed surface mercury concentration varied between 0.1 and 0.8 ppm, which is up to 20 times the control value. Generally the surface concentration was between 0.2 and 0.4 ppm.

The effect of sedimentation rate on these concentration-depth profiles can be seen by the two different slopes for these profiles. The concentration in core 63 decreases at a much slower rate than that for core 142. The average sedimentation rate was estimated by dividing the depth corresponding to a corrected concentration (observed value-0.031) of 0.02 ppm by 31 years. The value of 0.02 ppm was chosen because it represents the minimum difference between background values that we can realistically measure. The time period of 31 years corresponds to the time between 1941, which is our estimate of when mercury input began, and 1972, when the cores were collected.

The variation of mercury concentration with depth going across Sandusky

Bay is shown by Figure 7. Cross section 122-13 compares the mercury concentration depth profiles for cores going from west to east across the west bay. The mercury values on these profiles are not corrected for background. These linear plots show that the initial increase in mercury concentration above the control or background value was very subtle. This point is best seen on semilog or log-log plots of mercury concentration and depth such as figure 6. Thus the sedimentation rates to follow represent maximum values. The major increase in mercury concentration is generally much later than the point we estimate corresponds to the beginning of mercury input.

The second cross section 138-150 shows the mercury profile across the east bay. The pollution level in this area is much lower. Some cores such as 138 may show evidence of scour or 145 may show evidence of dredging, because they contain a disproportionate thickness of constant enriched zone at the surface. Both of these cross sections serve to illustrate that the west bay and the east bay act as separate depositional basins. They are separated by a narrow area where the Bass Island Group (Silurian dolomites) crops out. Very little deposition has occurred across this bedrock high.

The sedimentation rates calculated for the Sandusky Bay cores using the method of Wolery and Walters (1974) show a logical pattern (figure 8) that is consistent with the bedrock geology described by Forsyth (1975). The values near shore were consistently less than those in the center portions of the west and east bays. The sedimentation rates reach a maximum of 2.0 cm/year in the west bay and 1.7 cm/year in the east bay. These sedimentation rates are higher than normally observed in Western Lake Erie (Wolery and

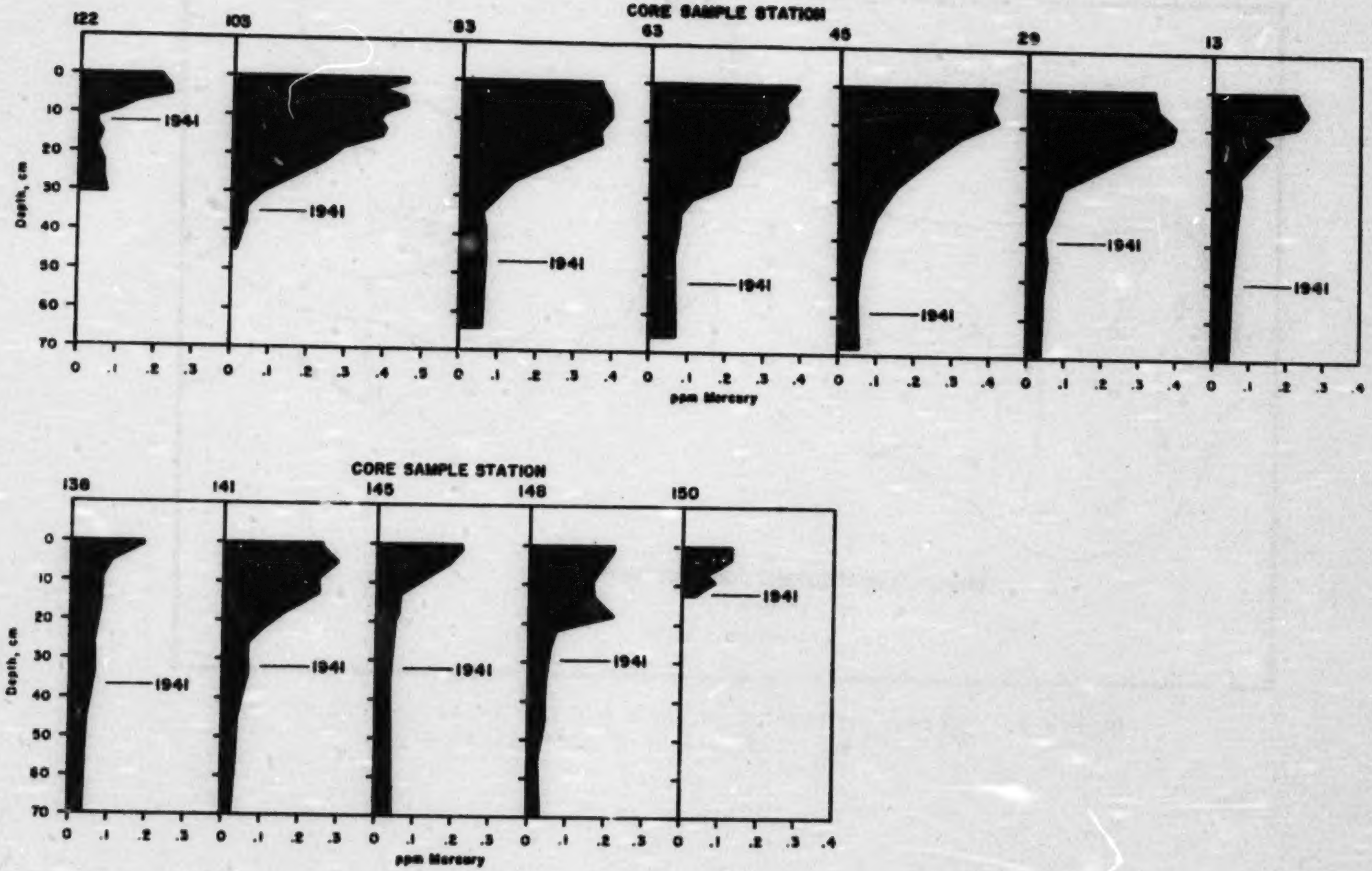

Figure 7. Cross sections of west Sandusky Bay (stations 122 to 13) and east Sandusky Bay (stations 138 to 150) showing the mercury concentration in the sediments as a function of depth.

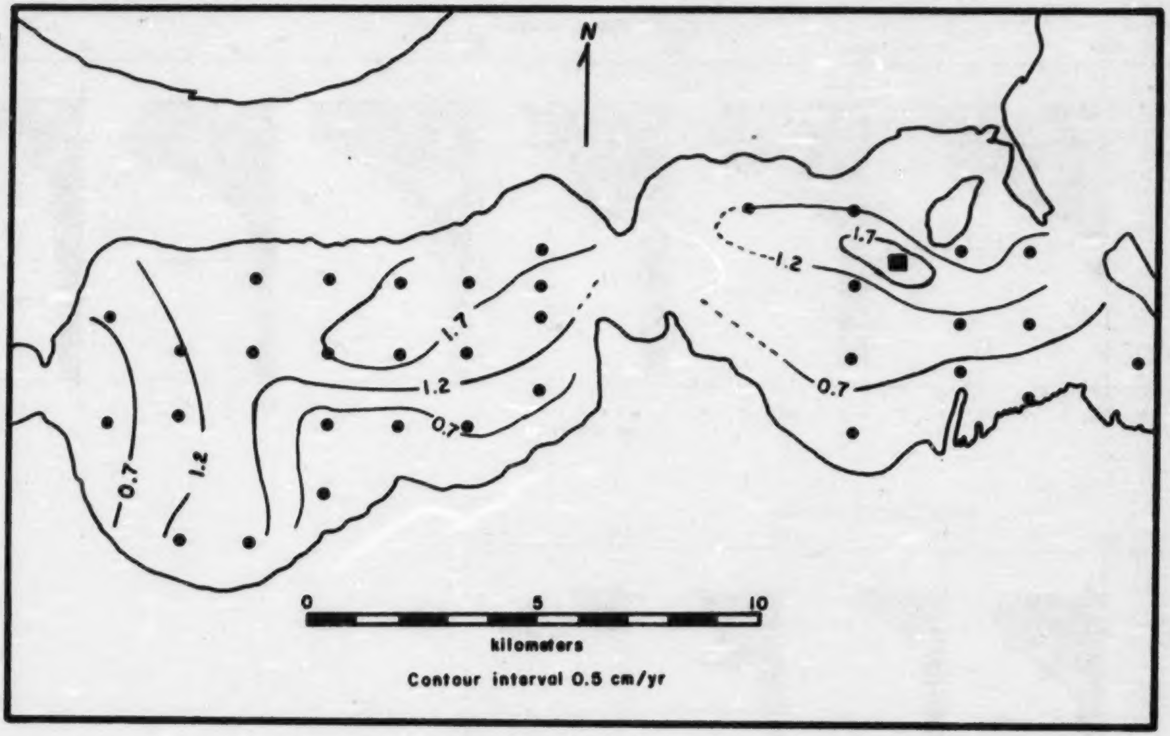
N
1.7
1.2
0.7
1.7
1.2
0.7
1.2
0.7
0
5
10
kilometers
Contour interval 0.5 cm/yr

Figure 8. Average sedimentation rate map for Sandusky Bay. The sedimentation rates are given in cm/yr.

Table 1: Mercury and Sediment loads in Sandusky Bay sediment deposited since 1941.

	West Bay	East Bay	Total
Mercury load (kg Hg)	2,500	1,000	3,500
Sediment load (10^9kg)	16.	9.4	2.5
Area (km^2)	63.0	44.5	107.5
Average Mercury Concentration (ppm)	0.16	0.11	.14
Mercury/Area ratio (kh Hg/km^2)	40	23	33
Sediment/Area ratio (10^8kg/Km^2)	2.5	2.1	2.3

Walters, 1974; Walters and Herdendorf, 1975) and comparable to those reported by Carter _et al_. (1975). The maximum sediment deposition was observed in a strip along the axis of the west bay. The sediment deposition also increased going away from the mouth of the Sandusky River.

The effects of sedimentation are summarized in Table 1 which shows the sediment and mercury loads of material deposited in Sandusky Bay since 1941. The total mercury load (3.5 metric tons) is only 1.5 percent of the 228 metric tons reported for western Lake Erie by Walters _et al_. (1974). Therefore, Sandusky Bay and the apparent source on the Sandusky River in the vicinity of Bucyrus, Ohio, (figure 5) are of minor importance when considering the Lake Erie system.

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APPENDIX 1. RESULTS OF ANALYSES OF SANDUSKY BAY SEDIMENT CORES FOR MERCURY, CHROMIUM, AND NICKEL

STATION	CORE	INTERVAL TOP	BOTTCM	WATER %	WET HG PPM	DRY HG PPM	CR PPM	NI PPM
11	1	0.0	2.0	64	0.100	0.280	28.0	40.0
11	1	4.0	6.0	66	0.110	0.310	28.0	44.0
11	1	8.0	10.0	62	0.120	0.310	26.0	43.0
11	1	10.0	12.0	58	0.090	0.220	26.0	38.0
11	1	12.0	14.0	49	0.073	0.140	22.0	37.0
11	1	16.0	20.0	49	0.039	0.076	23.0	40.0
11	1	20.0	24.0	54	0.014	0.032	24.0	37.0
11	1	24.0	28.0	50	0.022	0.043	22.0	40.0
11	1	28.0	32.0	50	0.019	0.038	19.0	35.0
13	1	0.0	2.0	50	0.120	0.230	25.0	41.0
13	1	4.0	6.0	51	0.120	0.250	24.0	39.0
13	1	8.0	10.0	48	0.120	0.230	25.0	38.0
13	1	10.0	12.0	50	0.064	0.130	23.0	39.0
13	1	12.0	14.0	51	0.080	0.160	27.0	39.0
13	1	16.0	20.0	51	0.054	0.110	25.0	41.0
13	1	20.0	24.0	52	0.036	0.075	24.0	38.0
13	1	24.0	28.0	53	0.037	0.078	26.0	40.0
13	1	32.0	36.0	55	0.030	0.067	23.0	42.0
13	1	40.0	50.0	52	0.026	0.055	27.0	46.0
13	1	50.0	60.0	45	0.026	0.048	20.0	35.0
13	1	66.0	72.0	39	0.027	0.043	17.0	31.0
14	1	0.0	2.0	43	0.110	0.180	19.0	32.0
14	1	4.0	6.0	43	0.120	0.200	20.0	34.0
14	1	8.0	10.0	45	0.140	0.260	23.0	39.0
14	1	12.0	14.0	46	0.110	0.200	28.0	46.0
14	1	16.0	20.0	50	0.072	0.140	27.0	43.0
14	1	20.0	24.0	52	0.053	0.110	28.0	47.0
14	1	28.0	32.0	53	0.027	0.058	25.0	41.0
14	1	32.0	36.0	55	0.031	0.069	22.0	38.0
14	1	40.0	50.0	56	0.021	0.048	24.0	39.0
14	1	50.0	60.0	45	0.026	0.046	19.0	38.0
14	1	68.0	75.0	36	0.025	0.039	13.0	26.0
15	1	0.0	2.0	67	0.120	0.360	28.0	47.0
15	1	4.0	6.0	78	0.087	0.390	28.0	45.0
15	1	8.0	10.0	65	0.160	0.450	27.0	44.0
15	1	12.0	14.0	63	0.150	0.390	26.0	46.0
15	1	16.0	20.0	74	0.140	0.520	28.0	47.0
15	1	20.0	24.0	60	0.069	0.170	25.0	41.0
15	1	24.0	28.0	61	0.068	0.170	24.0	41.0

APPENDIX 1. (CONTINUED)

STATION	CORE	INTERVAL TOP	BOTTOM	WATER %	WET HG PPM	DRY HG PPM	CR PPM	NI PPM
15	1	32.0	36.0	45	0.046	0.084	22.0	39.0
15	1	36.0	40.0	62	0.020	0.054	24.0	40.0
15	1	40.0	50.0	53	0.027	0.059	20.0	43.0
15	1	58.0	66.0	42	0.033	0.058	21.0	42.0
27	1	0.0	2.0	69	0.099	0.310	27.0	47.0
27	1	4.0	6.0	67	0.100	0.300	27.0	43.0
27	1	8.0	10.0	62	0.110	0.290	25.0	43.0
27	1	12.0	14.0	53	0.100	0.220	21.0	37.0
27	1	16.0	20.0	51	0.041	0.084	19.0	32.0
27	1	20.0	24.0	50	0.020	0.041	21.0	36.0
27	1	24.0	28.0	45	0.019	0.035	14.0	29.0
27	1	35.0	38.0	41	0.025	0.043	28.0	43.0
29	1	0.0	2.0	57	0.150	0.340	25.0	42.0
29	1	4.0	6.0	56	0.150	0.350	28.0	42.0
29	1	8.0	10.0	57	0.170	0.400	26.0	46.0
29	1	12.0	14.0	57	0.170	0.390	25.0	44.0
29	1	16.0	20.0	59	0.110	0.260	26.0	45.0
29	1	24.0	28.0	54	0.044	0.094	23.0	42.0
29	1	32.0	36.0	51	0.033	0.067	23.0	45.0
29	1	36.0	40.0	62	0.018	0.047	26.0	41.0
29	1	40.0	50.0	52	0.026	0.054	21.0	40.0
29	1	50.0	60.0	54	0.018	0.039	24.0	40.0
29	1	70.0	77.0	38	0.025	0.040	15.0	29.0
31	1	0.0	2.0	53	0.170	0.360	25.0	40.0
31	1	4.0	6.0	53	0.180	0.390	23.0	38.0
31	1	8.0	10.0	54	0.170	0.370	24.0	43.0
31	1	12.0	14.0	52	0.200	0.420	26.0	50.0
31	1	16.0	20.0	57	0.130	0.290	25.0	44.0
31	1	24.0	28.0	55	0.092	0.200	22.0	44.0
31	1	32.0	36.0	56	0.062	0.140	24.0	49.0
31	1	40.0	50.0	53	0.034	0.071	22.0	45.0
31	1	50.0	60.0	57	0.024	0.056	27.0	45.0
31	1	66.0	71.0	44	0.029	0.052	19.0	42.0
43	1	0.0	2.0	60	0.140	0.360	26.0	47.0
43	1	4.0	6.0	68	0.110	0.350	28.0	48.0
43	1	8.0	10.0	61	0.140	0.370	24.0	43.0
43	1	12.0	14.0	55	0.110	0.240	26.0	44.0
43	1	16.0	20.0	56	0.076	0.170	24.0	44.0
43	1	20.0	24.0	40	0.022	0.037	26.0	39.0
43	1	24.0	28.0	34	0.0	0.0	29.0	43.0
43	1	24.0	28.0	35	0.023	0.036	26.0	40.0

APPENDIX 1. (CONTINUED)

STATION	CORE	INTERVAL TOP	BOTTOM	WATER %	WET HG PPM	DRY HG PPM	CR PPM	NI PPM
43	1	28.0	32.0	39	0.019	0.032	0.0	0.0
43	1	32.0	35.0	37	0.029	0.046	32.0	47.0
45	1	0.0	2.0	59	0.170	0.410	28.0	44.0
45	1	4.0	6.0	57	0.170	0.400	24.0	45.0
45	1	8.0	10.0	57	0.180	0.420	25.0	44.0
45	1	12.0	14.0	54	0.150	0.320	28.0	43.0
45	1	16.0	20.0	59	0.100	0.250	27.0	45.0
45	1	24.0	28.0	58	0.064	0.150	27.0	45.0
45	1	32.0	36.0	60	0.038	0.094	27.0	43.0
45	1	40.0	50.0	50	0.030	0.060	25.0	45.0
45	1	50.0	60.0	61	0.019	0.048	22.0	37.0
45	1	60.0	68.0	40	0.033	0.054	16.0	29.0
47	1	0.0	2.0	69	0.120	0.380	27.0	41.0
47	1	4.0	6.0	48	0.180	0.340	25.0	38.0
47	1	8.0	10.0	44	0.190	0.340	25.0	39.0
47	1	12.0	14.0	41	0.120	0.210	24.0	39.0
47	1	16.0	20.0	51	0.057	0.120	25.0	43.0
47	1	24.0	28.0	53	0.046	0.097	26.0	43.0
47	1	32.0	36.0	52	0.035	0.072	23.0	42.0
47	1	40.0	46.0	45	0.035	0.063	21.0	39.0
59	1	0.0	2.0	46	0.150	0.270	25.0	44.0
59	1	4.0	6.0	52	0.100	0.220	25.0	44.0
59	1	8.0	10.0	41	0.042	0.070	26.0	44.0
59	1	10.0	12.0	34	0.046	0.069	25.0	42.0
59	1	12.0	14.0	32	0.022	0.032	24.0	42.0
61	1	0.0	2.0	52	0.069	0.140	29.0	46.0
61	1	4.0	6.0	43	0.057	0.100	29.0	46.0
61	1	6.0	8.0	38	0.190	0.310	28.0	45.0
61	1	8.0	10.0	32	0.160	0.230	26.0	44.0
61	1	10.0	12.0	38	0.087	0.140	23.0	43.0
61	1	12.0	14.0	44	0.025	0.045	24.0	42.0
61	1	14.0	16.0	49	0.047	0.093	22.0	43.0
61	1	16.0	20.0	45	0.049	0.090	24.0	45.0
61	1	24.0	28.0	46	0.042	0.079	26.0	46.0
61	1	36.0	40.0	51	0.034	0.068	25.0	46.0
61	1	46.0	52.0	58	0.026	0.061	26.0	44.0
63	1	0.0	2.0	59	0.160	0.390	26.0	43.0
63	1	4.0	6.0	60	0.140	0.350	25.0	43.0
63	1	8.0	10.0	57	0.160	0.360	25.0	41.0
63	1	12.0	14.0	55	0.150	0.340	19.0	42.0

APPENDIX 1. (CONTINUED)

STATION	CORE	INTERVAL TOP	INTERVAL BOTTOM	WATER %	WET HG PPM	DRY HG PPM	CR PPM	NI PPM
63	1	16.0	20.0	61	0.110	0.270	25.0	41.0
63	1	24.0	28.0	61	0.082	0.210	25.0	42.0
63	1	28.0	32.0	59	0.046	0.110	22.0	41.0
63	1	32.0	36.0	58	0.033	0.078	24.0	45.0
63	1	36.0	40.0	65	0.028	0.079	22.0	40.0
63	1	40.0	50.0	59	0.027	0.064	25.0	44.0
63	1	58.0	66.0	57	0.031	0.071	25.0	43.0
65	1	0.0	2.0	83	0.052	0.310	27.0	41.0
65	1	4.0	6.0	68	0.110	0.340	26.0	41.0
65	1	8.0	10.0	61	0.150	0.380	27.0	41.0
65	1	12.0	14.0	55	0.130	0.310	25.0	40.0
65	1	16.0	20.0	59	0.088	0.210	26.0	41.0
65	1	24.0	26.5	52	0.053	0.110	27.0	42.0
78	1	0.0	2.0	66	0.110	0.330	24.0	41.0
78	1	2.0	4.0	64	0.140	0.390	25.0	41.0
78	1	4.0	6.0	63	0.130	0.350	24.0	37.0
78	1	6.0	8.0	63	0.150	0.420	24.0	39.0
78	1	8.0	10.0	59	0.130	0.320	22.0	39.0
78	1	10.0	12.0	55	0.130	0.290	20.0	36.0
78	1	12.0	14.0	52	0.089	0.190	20.0	40.0
78	1	14.0	16.0	53	0.062	0.130	22.0	37.0
78	1	16.0	20.0	56	0.068	0.160	23.0	41.0
78	1	20.0	24.0	55	0.042	0.092	25.0	41.0
78	1	24.0	28.0	56	0.034	0.079	22.0	44.0
78	1	28.0	32.0	48	0.036	0.070	20.0	41.0
78	1	32.0	37.0	52	0.032	0.066	21.0	43.0
83	1	0.0	2.0	57	0.160	0.370	26.0	41.0
83	1	4.0	6.0	53	0.180	0.390	25.0	41.0
83	1	8.0	10.0	55	0.180	0.390	27.0	41.0
83	1	12.0	14.0	51	0.180	0.370	26.0	42.0
83	1	16.0	20.0	63	0.140	0.370	25.0	40.0
83	1	20.0	24.0	58	0.100	0.240	24.0	41.0
83	1	24.0	28.0	60	0.056	0.140	24.0	41.0
83	1	32.0	36.0	57	0.040	0.093	24.0	41.0
83	1	36.0	40.0	56	0.029	0.067	23.0	44.0
83	1	40.0	50.0	61	0.026	0.065	26.0	43.0
83	1	57.0	64.0	47	0.031	0.060	21.0	35.0
85	1	0.0	2.0	49	0.240	0.460	25.0	41.0
85	1	2.0	4.0	48	0.240	0.460	23.0	39.0
85	1	4.0	6.0	45	0.200	0.370	22.0	38.0
85	1	6.0	8.0	41	0.260	0.440	23.0	41.0

APPENDIX 1. (CONTINUED)

STATION	CORE	INTERVAL		WATER	WET HG	DRY HG	CR	NI
		TOP	BOTTOM	%	PPM	PPM	PPM	PPM
85	1	8.0	10.0	48	0.230	0.430	20.0	38.0
85	1	10.0	12.0	49	0.160	0.310	20.0	41.0
85	1	12.0	14.0	51	0.150	0.320	24.0	35.0
85	1	14.0	16.0	53	0.110	0.230	21.0	38.0
85	1	16.0	20.0	57	0.090	0.210	21.0	38.0
85	1	20.0	24.0	56	0.056	0.130	19.0	35.0
85	1	24.0	28.0	57	0.052	0.120	20.0	37.0
85	1	28.0	32.0	63	0.054	0.150	21.0	37.0
85	1	32.0	36.0	55	0.033	0.073	0.0	37.0
85	1	36.0	40.0	57	0.024	0.057	22.0	41.0
85	1	40.0	44.0	51	0.050	0.100	0.0	38.0
100	1	0.0	2.0	49	0.190	0.380	23.0	42.0
100	1	2.0	4.0	48	0.200	0.380	24.0	41.0
100	1	4.0	6.0	48	0.200	0.400	22.0	36.0
100	1	6.0	8.0	43	0.230	0.400	23.0	37.0
100	1	8.0	10.0	41	0.160	0.270	16.0	27.0
100	1	10.0	12.0	45	0.120	0.210	23.0	37.0
100	1	12.0	14.0	43	0.120	0.220	22.0	35.0
100	1	14.0	16.0	44	0.100	0.190	22.0	38.0
100	1	16.0	20.0	45	0.058	0.110	26.0	42.0
100	1	20.0	24.0	46	0.070	0.130	24.0	40.0
100	1	24.0	28.0	46	0.081	0.150	27.0	44.0
100	1	28.0	32.0	43	0.024	0.043	22.0	33.0
100	1	32.0	35.0	46	0.069	0.130	20.0	40.0
103	1	0.0	2.0	56	0.200	0.460	21.0	28.0
103	1	2.0	4.0	56	0.170	0.390	21.0	39.0
103	1	4.0	6.0	58	0.190	0.450	22.0	31.0
103	1	6.0	8.0	57	0.220	0.520	24.0	37.0
103	1	8.0	10.0	57	0.170	0.400	23.0	35.0
103	1	10.0	12.0	51	0.190	0.380	19.0	31.0
103	1	12.0	14.0	52	0.190	0.400	17.0	30.0
103	1	14.0	16.0	51	0.190	0.390	22.0	38.0
103	1	16.0	20.0	49	0.150	0.290	15.0	28.0
103	1	20.0	24.0	48	0.120	0.240	18.0	31.0
103	1	24.0	28.0	48	0.085	0.160	17.0	33.0
103	1	28.0	32.0	46	0.044	0.081	18.0	32.0
103	1	32.0	36.0	45	0.022	0.039	16.0	31.0
103	1	36.0	40.0	39	0.023	0.038	13.0	24.0
103	1	40.0	50.0	49	0.006	0.011	9.2	27.0
103	1	50.0	60.0	57	0.068	0.160	9.3	31.0
105	1	0.0	2.0	59	0.140	0.340	25.0	36.0
105	1	4.0	6.0	58	0.140	0.330	24.0	37.0

APPENDIX 1. (CONTINUED)

STATION	CORE	INTERVAL TOP	INTERVAL BOTTOM	WATER %	WET HG PPM	DRY HG PPM	CR PPM	NI PPM
105	1	8.0	10.0	51	0.160	0.330	20.0	31.0
105	1	12.0	14.0	42	0.210	0.360	19.0	31.0
105	1	16.0	20.0	39	0.110	0.180	23.0	37.0
122	1	0.0	2.0	38	0.140	0.220	11.0	19.0
122	1	2.0	4.0	34	0.160	0.240	10.0	18.0
122	1	4.0	6.0	30	0.160	0.230	9.3	15.0
122	1	6.0	8.0	29	0.110	0.160	8.2	16.0
122	1	8.0	10.0	26	0.079	0.110	7.3	13.0
122	1	10.0	12.0	27	0.036	0.049	7.2	14.0
122	1	12.0	14.0	27	0.035	0.047	7.9	15.0
122	1	14.0	16.0	27	0.046	0.064	7.6	16.0
122	1	16.0	20.0	33	0.035	0.052	7.0	15.0
122	1	20.0	24.0	31	0.045	0.065	7.8	18.0
122	1	24.0	28.0	29	0.048	0.068	8.8	18.0
122	1	28.0	30.5	25	0.056	0.075	9.9	19.0
125	1	0.0	2.0	62	0.110	0.300	22.0	32.0
125	1	4.0	6.0	45	0.160	0.290	15.0	22.0
125	1	8.0	10.0	39	0.150	0.240	14.0	21.0
125	1	12.0	14.0	29	0.130	0.180	11.0	19.0
125	1	14.0	16.0	28	0.073	0.100	10.0	19.0
125	1	16.0	20.0	27	0.025	0.035	8.3	14.0
125	1	20.0	24.0	26	0.014	0.019	7.7	12.0
125	1	28.0	31.0	33	0.025	0.037	23.0	33.0
138	1	0.0	2.0	45	0.100	0.190	24.0	44.0
138	1	4.0	6.0	48	0.056	0.110	25.0	44.0
138	1	8.0	10.0	58	0.036	0.085	28.0	45.0
138	1	12.0	14.0	48	0.043	0.082	28.0	42.0
138	1	16.0	20.0	53	0.038	0.080	28.0	45.0
138	1	24.0	28.0	43	0.032	0.055	20.0	36.0
138	1	32.0	36.0	42	0.040	0.069	20.0	36.0
138	1	40.0	50.0	50	0.023	0.046	21.0	35.0
138	1	60.0	70.0	42	0.020	0.035	27.0	33.0
138	1	80.0	88.0	36	0.020	0.032	25.0	32.0
140	1	0.0	2.0	56	0.120	0.260	25.0	40.0
140	1	4.0	6.0	55	0.120	0.280	23.0	39.0
140	1	8.0	10.0	56	0.120	0.260	27.0	39.0
140	1	12.0	14.0	56	0.110	0.240	26.0	39.0
140	1	14.0	16.0	60	0.071	0.180	21.0	40.0
140	1	16.0	20.0	58	0.051	0.120	22.0	39.0
140	1	24.0	28.0	60	0.027	0.067	24.0	42.0
140	1	32.0	36.0	59	0.026	0.064	23.0	39.0

APPENDIX 1. (CONTINUED)

STATION	CORE	INTERVAL TOP	INTERVAL BOTTOM	WATER %	WET HG PPM	DRY HG PPM	CR PPM	NI PPM
140	1	36.0	40.0	55	0.021	0.048	19.0	36.0
140	1	40.0	50.0	54	0.025	0.054	20.0	35.0
140	1	70.0	77.0	39	0.030	0.049	15.0	28.0
141	1	0.0	2.0	54	0.120	0.260	23.0	39.0
141	1	4.0	6.0	52	0.140	0.290	26.0	40.0
141	1	8.0	10.0	52	0.120	0.250	40.0	47.0
141	1	12.0	14.0	55	0.110	0.250	26.0	47.0
141	1	16.0	20.0	61	0.063	0.160	24.0	41.0
141	1	20.0	24.0	59	0.042	0.100	21.0	38.0
141	1	24.0	28.0	49	0.035	0.068	21.0	37.0
141	1	32.0	36.0	47	0.034	0.065	16.0	36.0
141	1	40.0	50.0	49	0.019	0.037	17.0	36.0
141	1	50.0	60.0	41	0.021	0.036	16.0	29.0
141	1	66.0	72.0	31	0.017	0.024	8.2	17.0
142	1	0.0	2.0	55	0.096	0.210	22.0	40.0
142	1	4.0	6.0	50	0.100	0.210	23.0	39.0
142	1	8.0	10.0	50	0.110	0.220	22.0	38.0
142	1	12.0	14.0	48	0.071	0.140	18.0	34.0
142	1	16.0	20.0	48	0.032	0.062	19.0	38.0
142	1	24.0	28.0	55	0.022	0.049	21.0	38.0
142	1	28.0	32.0	56	0.021	0.049	17.0	36.0
142	1	32.0	36.0	50	0.020	0.041	19.0	36.0
142	1	40.0	50.0	42	0.014	0.024	15.0	29.0
142	1	50.0	59.0	47	0.023	0.042	20.0	34.0
142	1	59.0	67.0	51	0.020	0.041	18.0	40.0
143	1	0.0	2.0	63	0.074	0.200	27.0	46.0
143	1	2.0	4.0	61	0.082	0.210	23.0	45.0
143	1	4.0	6.0	55	0.085	0.210	21.0	38.0
143	1	6.0	8.0	58	0.086	0.210	25.0	45.0
143	1	8.0	10.0	56	0.083	0.190	23.0	43.0
144	1	0.0	2.0	56	0.093	0.210	24.0	44.0
144	1	4.0	6.0	56	0.130	0.290	24.0	41.0
144	1	12.0	14.0	53	0.130	0.280	22.0	37.0
144	1	16.0	20.0	46	0.096	0.180	18.0	34.0
144	1	20.0	24.0	41	0.064	0.110	16.0	30.0
144	1	24.0	28.0	42	0.041	0.071	16.0	31.0
144	1	28.0	32.0	37	0.027	0.043	14.0	26.0
144	1	32.0	36.0	37	0.028	0.045	14.0	28.0
144	1	40.0	50.0	38	0.023	0.037	15.0	32.0
144	1	60.0	71.0	44	0.020	0.035	15.0	33.0

APPENDIX 1. (CONTINUED)

STATION	CORE	INTERVAL TOP	INTERVAL BOTTOM	WATER %	WET HG PPM	DRY HG PPM	CR PPM	NI PPM
145	1	0.0	2.0	51	0.110	0.220	22.0	41.0
145	1	4.0	6.0	46	0.100	0.190	21.0	41.0
145	1	8.0	10.0	46	0.062	0.110	18.0	36.0
145	1	12.0	14.0	48	0.033	0.064	18.0	36.0
145	1	16.0	20.0	49	0.028	0.055	17.0	36.0
145	1	28.0	32.0	53	0.024	0.050	16.0	35.0
145	1	32.0	36.0	49	0.022	0.044	16.0	35.0
145	1	40.0	50.0	44	0.021	0.038	15.0	34.0
145	1	66.0	72.0	45	0.026	0.046	16.0	38.0
146	1	0.0	2.0	56	0.033	0.074	19.0	39.0
146	1	4.0	6.0	34	0.046	0.069	18.0	40.0
146	1	8.0	10.0	31	0.043	0.062	21.0	42.0
146	1	12.0	14.0	36	0.035	0.054	19.0	40.0
146	1	16.0	20.0	45	0.029	0.052	20.0	40.0
146	1	24.0	28.0	41	0.028	0.047	16.0	33.0
146	1	32.0	36.0	48	0.025	0.048	19.0	38.0
146	1	40.0	46.0	47	0.026	0.049	19.0	40.0
147	1	0.0	2.0	32	0.077	0.110	10.0	19.0
147	1	4.0	6.0	27	0.079	0.110	8.2	15.0
147	1	8.0	10.0	27	0.069	0.094	8.5	15.0
147	1	12.0	14.0	32	0.097	0.140	12.0	22.0
147	1	16.0	20.0	34	0.100	0.150	13.0	21.0
147	1	24.0	28.0	29	0.077	0.110	11.0	18.0
147	1	28.0	32.0	27	0.054	0.075	11.0	17.0
147	1	32.0	36.0	30	0.050	0.071	12.0	20.0
147	1	36.0	39.0	26	0.049	0.066	9.9	17.0
147	1	39.0	42.0	25	0.039	0.052	7.7	14.0
148	1	0.0	2.0	47	0.120	0.220	23.0	38.0
148	1	4.0	6.0	44	0.110	0.190	24.0	38.0
148	1	8.0	10.0	45	0.091	0.170	23.0	40.0
148	1	12.0	14.0	47	0.090	0.170	21.0	37.0
148	1	16.0	20.0	47	0.120	0.220	20.0	35.0
148	1	20.0	24.0	49	0.036	0.071	21.0	36.0
148	1	24.0	28.0	43	0.033	0.058	18.0	31.0
148	1	32.0	36.0	38	0.028	0.046	12.0	22.0
148	1	36.0	40.0	34	0.029	0.043	11.0	22.0
148	1	40.0	50.0	38	0.027	0.044	14.0	26.0
148	1	50.0	60.0	21	0.018	0.027	11.0	21.0
148	1	70.0	79.0	40	0.020	0.033	15.0	31.0
149	1	0.0	2.0	50	0.160	0.320	30.0	47.0
149	1	4.0	6.0	48	0.160	0.320	30.0	45.0

APPENDIX 1. (CONTINUED)

STATION	CORE	INTERVAL		WATER	WET HG	DRY HG	CR	NI
		TOP	BOTTOM	%	PPM	PPM	PPM	PPM
149	1	8.0	10.0	47	0.130	0.250	27.0	42.0
149	1	10.0	12.0	43	0.066	0.120	17.0	31.0
149	1	12.0	14.0	42	0.026	0.045	14.0	30.0
149	1	16.0	20.0	40	0.023	0.038	12.0	27.0
149	1	20.0	24.0	33	0.014	0.021	14.0	23.0
149	1	24.0	27.0	25	0.019	0.026	16.0	34.0
150	1	0.0	2.0	37	0.083	0.130	19.0	26.0
150	1	2.0	4.0	36	0.085	0.130	18.0	28.0
150	1	4.0	6.0	33	0.068	0.100	12.0	19.0
150	1	6.0	8.0	29	0.047	0.067	10.0	18.0
150	1	8.0	10.0	29	0.060	0.084	7.9	15.0
150	1	10.0	12.5	26	0.026	0.035	8.9	13.0

APPENDIX 2. RESULTS OF ANALYSES OF SANDUSKY RIVER, BROKEN SWORD CREEK, AND TYMOCHTEE CREEK SEDIMENTS FOR MERCURY, CHROMIUM, AND NICKEL

STATION	CORE	WATER %	WET HG PPM	DRY HG PPM	CR PPM	NI PPM
35	2	39	0.028	0.046	7.1	10.0
41	2	74	0.015	0.059	15.0	21.0
63	2	74	0.018	0.071	15.0	23.0
82	2	68	0.010	0.031	16.0	27.0
98	2	97	0.003	0.086	14.0	24.0
134	2	57	0.036	0.084	13.0	23.0
143	2	50	0.021	0.042	11.0	17.0
175	2	80	0.011	0.057	8.1	12.0
187	1	48	0.360	0.700	17.0	22.0
187	2	75	0.170	0.710	17.0	12.0
193	1	43	0.087	0.150	14.0	28.0
195	1	73	0.027	0.099	22.0	36.0
207	2	85	0.021	0.140	18.0	27.0
0.5	2	68	0.010	0.031	13.0	24.0
5.6	2	56	0.008	0.018	15.0	23.0
9.2	2	48	0.019	0.036	9.4	14.0
15.0	2	76	0.009	0.039	16.0	27.0
29.7	2	50	0.009	0.018	12.0	19.0
43.9	2	50	0.013	0.027	12.0	22.0
64.1	2	51	0.012	0.025	15.0	29.0
76.3	2	68	0.009	0.028	12.0	29.0
1.3	2	73	0.005	0.019	8.9	17.0
18.7	2	74	0.010	0.040	15.0	31.0
26.7	2	72	0.008	0.029	14.0	22.0
39	2	80	0.011	0.052	14.0	33.0
54	2	55	0.019	0.041	18.0	29.0

ABSTRACT

MATERIALS BALANCE IN KILLDEER RESERVOIR

J.W KRAMER AND D.B. BAKER

Heidelberg College, Tiffin, Ohio

Killdeer Reservoir in Wyandot County is a multipurpose upground reservoir typical of those proposed in the Northwest Ohio Water Development Plan. The reservoir has a surface area of about 275 acres, a mean depth of 25 ft. and a capacity of 2.2 billion gallons. During periods of high stream flows, usually in the winter and the spring, water is pumped into the reservoir. Releases from Killdeer Reservoir provide flow augmentation. Other upground reservoirs often provide municipal and industrial water supplies.

Since volumes of both input and release water are continuously monitored, these reservoirs are ideally suited for materials balance studies. The reservoir dikes prevent surface runoff from entering the reservoir. During the intial filling of the reservoir approximately 30% of the input volume was monitored for ortho and total phosphorous, ammonia, Ca, Mg, Na, K, Fe, Cu, Mn, suspending solids and conductivity. The resulting loading figures were extrapolated to estimate the inital material input into the reservoir.

Water quality measurements within the reservoir have allowed calculation of the distribution of material between the water column and the reservoir sediments. Additional input/output measurement during water releases and pumping provide a continuing material budget for the reservoir.

A study is currently underway to investigate the relationship between morphometry, throughput/volume ratios, seasonal patterns of pumping and withdrawal and reservoir water quality. Since upground reservoirs offer a variety of management possibilities, including decisions on morphometry prior to construction, studies of their general limnology may be of considerable interest.

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ABSTRACT

BENTHIC INVERTEBRATES IN TWO UPGROUND RESERVOIRS IN THE SANDUSKY RIVER BASIN

R. E. DAY

Ohio Division of Wildlife, Inland Fisheries Research, Findlay, Ohio

The benthic invertebrate populations of Killdeer and Beaver Creek Reservoirs were studied from December 1971 thru November 1972.

Stratified random samples were taken in replicate on a monthly basis from six stations in Killdeer Reservoir and three stations in Beaver Creek Reservoir. Samples were collected with a Petersen dredge (800 cm^2) and screened with a No. 30 U.S. Standard sieve. All invertebrates were identified to the lowest possible taxa and expressed as mean number per square meter.

A total of 30 to 36 taxa were identified from Beaver Creek and Killdeer Reservoirs, respectively. Members of the dipteran family Chironomidae were the predominant invertebrates inhabiting both reservoirs during the first year of impoundment. *Procladius* and *Chironomus* were the most abundant and ubiquitous chironoid genera found. The baetid mayfly *Caenis* and the leptocerid caddisfly *Oecetis* were the most abundant invertebrates found in the shallow areas of both reservoirs.

The conservation pools of both reservoirs became anaerobic during the summer stagnation period. This condition decreased the invertebrate populations both qualitatively and quantitatively.

Studies of the benthic invertebrate populations will continue until 1976 as it has been found that they are a major source of forage for the exisiting fish populations.

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ABSTRACT

FISH POPULATIONS IN UPGROUND RESERVOIRS OF THE SANDUSKY RIVER BASIN

K. O. PAXTON

Ohio Division of Wildlife, Inland Fisheries Research, Findlay, Ohio

The numerous and varied stocking programs which have been used by the Ohio Division of Wildlife have provided a nearly equal number of resultant fish population structures in Ohio's upground reservoirs. Species normally stocked have included bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides)*, smallmouth bass (*Micropterus dolomieui*), walleye *(Stizostedion vitreum vitreum)*, brown bullhead *(Ictalurus nebulosus)*, and channel catfish (*Ictalurus punctatus)*. Both yellow perch *(Perca flavascens)* and white bass *(Morone chrysops)* have been introduced into many uprground reservoirs and are still present where introduced.

Studies conducted by Ohio's Inland Fisheries Research Unit have indicated the species best able to utilize the productive potential of most upground reservoirs include yellow perch, bluegill, and white crappie (*Pomoxis annularis*). These species normally dominate the fish population structure of upground reservoirs considered to provide quality fishing.

The future emphasis of fisheries management of upground reservoirs may very likely be centered on these "panfish" species which attain rapid growth based on short food chains, provide large sustained yields to the angler, and thus most nearly optimize the sport fishery. Predators, such as walleye and black bass, will still be present but should not be expected to provide large angler harvests on a continuing basis.

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ABSTRACT

WATER RESOURCES INVESTIGATIONS OF THE U.S. GEOLOGICAL SURVEY WITH SPECIAL REFERENCE TO THE SANDUSKY RIVER BASIN, OHIO

J.F. BLAKEY AND A.O. WESTFALL

U.S. Geological Survey, Columbus, Ohio

The mission of the Water Resources Division, U.S. Geological Survey is to provide information on the nation's water resources. More than 18,000 stream-gaging stations, 28,000 observation wells, and 5,000 water-quality stations provide the information base. Much of the support for the Survey's investigation and data-collection activities is from cooperative programs with state, local, and other federal agencies.

The 11 stream-gaging stations, one observation well, and five water-quality stations in the Sandusky River basin are part of this national information base. Although small in both area and activities when compared to the national level, the water resources studies in the Sandusky River basin are important to the Geological Survey, the State, and most important to the residents of the Sandusky River basin.

Besides operating the network of stations and data collection sites, the U.S. Geological Survey carries out research and special studies of water resources. A recent time-of-travel study of selected streams in the Sandusky River basin is an example of these activities.

Using dye-tracer techniques, rates of dispersion and movement of water were measured. Rates of travel measured apply only to existing flow conditions, but these measurements can be used to estimate rates of travel during other flow conditions. Time of travel information is of utmost importance in monitoring the impact of pollutants on surface waters.

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ABSTRACT

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (N.P.D.E.S.) PERMITS AS THEY RELATE TO THE SANDUSKY RIVER BASIN

R. J. MANSON

Ohio Environmental Protection Agency, Bowling Green, Ohio

On March 11, 1974, Ohio obtained primary authority for the N.P.D.E.S. (National Pollutant Discharge Elimination System) permit system. This national system to "permit" discharges is required by P.L. 92-500 and is designed to develop and enforce consistent nationwide treatment and effluent standards with legally agreed upon time tables to meet these standards. In addition, the permits are designed to maintain and achieve water quality standards where possible by 1983 using the best available treatment economically achievable. In the case of municipal permits, the best practical control technology currently available is required by 1983. The main water quality strategy in the Sandusky Basin concerns the issuance of municipal permits. There are very few significant industrial discharges. Non-point sources have a substantial impact but are not covered under the permit system.

It's important to understand that most of the new construction demanded in the permit compliance time schedule is dependent on federal grants for financing. The schedule is written in such a way that the town can delay construction until they have received a construction grant.

Specific items covered in permit conditions, the compliance time schedule or the grant conditions include:

A. Elimination of treatment of overflows and bypasses
B. Phosphorous removal -- De-emphasis of nitrification
C. Attainment of water quality standards, particularly bacteria and oxygen
D. Pre-treatment of industrial wastes
E. Regionalization and cost effectiveness

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ABSTRACT

PAST AND PRESENT COPPERATION OF AGENCIES AND INSTITUTIONS INVOLVED WITH WATER QUALITY STUDIES AND A PROPOSED METHOD FOR IMPROVEMENT OF COOPERATION

JOHN R. ADAMS

Toledo Metropolitan Area Council of Governments, Toledo, Ohio

In the past, it is clear that there has been very little inter-agency cooperation in the planning and execution of water quality studies. It has not been uncommon for surveyors of different agencies to encounter one another in the field, and, upon comparison of notes, to find that they are performing similar studies. It is even more apparent that agencies and institutions have poor mechanisms for sharing the results of completed studies. Under the auspices pf Section 208 of P.L. 92-500, Areawide Wastewater Management Planning a Water Quality Data Task Group has been established to study and implement plans which will lead to greater inter-agency planning and sharing. A monograph will be published which will outline standard procedures for survey design, sampling procedures, analytical methods and the use of a common data base. These procedures will be localized to the streams of North Central Ohio which are tributary to Lake Erie. A computer data base will be established which will accept data from all subscribing agencies and which will be available to any person or agency which has need for water quality data.

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CITIZEN INPUT INTO LOCAL LAND USE

SHEILA DIGBY

League of Women Voters, Tiffin, Ohio 44883

The Tiffin League of Women Voters would like to thank the Symposium for inviting us to participate. I would like to recognize the following LWV members who were involved in the preparation of this material: Freddie Larson, Mary Lewis, Bonnie Cordell, Von Hill and Elinor Spellerberg.

The State and National League has long been interested in environmental quality, particularly in the area of water pollution, having had studies dating back to the 1950's. In the last few years, we have realized that the land is also a resource which must be protected. The National LWV adopted Land Use as a study item in 1972 and the Ohio LWV adopted it the following year. The Lake Erie Basin committee, an inter-League group from five states,was organized in 1963.

A National Land Use position was adopted this spring and we now are able to have our lobbyist testify and are able to participate in the legislative process which we hope will lead to improved land use. Our statement reads in part, "The LWV of U.S., recognizing that land is a finite resource, not just a commodity, believes that land ownership, whether public or private, implies responsibilities of stewardship." The statement includes appropriate suggestions covering such areas as levels of government responsibility, citizen participation and the use of critical land areas.

To me, one of the most difficult points of the position statement to get across is the point that land is a finite resource, not a commodity. Our history tells us that land is a commodity to be gained by conquest, our tax

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structure (established during a time when Ohio was largely agricultural) tells us that land is a commodity; and our economic system has deeply impressed upon us that land is a commodity to be bought and sold, hopefully for a profit.

The Tiffin League has an additional interest in the problems of land use through our study of City Planning, the Master Plan and our observation of the Planning Commission and City Council. It doesn't take long to see the problems arising from improper land us; however, the solutions are more difficult to perceive. The League also sponsored a conference on the Legal Aspects of Land Use last year in connection with Heidelberg College and the Farm Bureau.

When I first thought about citizen input into land use, my reaction was that it is absolutely nil. Then as I did some talking to others involved in land use, I realized that it is better described as "crisis oriented". No one cares too much about the river until it appears in their basement family room. Land fills are recognized as essential, but not across the road from my home. At this point the citizen becomesvitally interested in land use; however, he usually does not know where to go for information to learn who makes the decisions, and what rights he has or doesn't have. He then becomes very frustrated, encounters officials who may be equally frustrated while trying to do what they consider their job,and nothing worthwhile comes from the encounter. It is at this point that citizens become familiar with such land use tools as zoning, housing,and building codes and subdivision regulations.

However, they will find some groups locally that are concerned about the land and are interested in land use legislation. Among these groups are the Soil Conservation Service, the Farm Bureau, the Co-operative Extension Service, the Health Department, and the Planning Commission,to name a few.

At this point in the symposium, I would like to offer a challenge to the participants. Remember that you are citizens. Please give the public useable information. While I realize that these in depth studies that you are conducting are absolutely essential to understanding the river, I can't even pronounce some of your topic titles, much less ask an intelligent question. So, you are asked to use lay terms. Assume that a lay audience has very little, if any, technical background. Help citizens see the total river. I liked the fact that so many presentations began with a picture of the river. We have become such a specialized society that it is most difficult to see the larger picture. As one author put it,"In the minds of most citizens, planning evokes no clear cut concept; in the jargon of the advertising agency, no image is created." Let's give the river and the land an image that goes beyond an individual's scope.

When it comes time for detailed planning, we must be able to see how our actions affect all parts of the river. We now tend to view flood control as simply moving the flood from our doorstep. What happens to the flood when it reaches someone else's doorstep is not our concern. But it should be,because it is possible we could have provided another alternative for the flood,such as not building on a flood plain.

Another challenge for members of the symposium is to participate in land use decisions,and I think perhaps many of you already have. Many laws already on the books have citizen participation written into them (for example, 1972 Federal Water Pollution Control Act, section 208 which has land use ramifications.)

Attend public hearings; speak up when asked; use your position to promote sound land use planning. There is a booklet entitled "Don't Leave It All to the Experts" which lists detailed citizen action. It gives details in such areas as how to become informed, how to know the laws before you act; how to pick targets for action; how to lobby; how to get funding; how to inform the public through the press, radio, and TV; and how to take definitive action. This booklet, printed by the Environmental Protection Agency (EPA) states that the EPA believes that public participation is a must if we are to have an environment fit for people. EPA also believes that public participation is most effective when concerned individuals combine and coordinate their efforts into environmental action through voluntary citizen organization.

A quotation worth repeating comes from a group with the acronym GASP (Group Against Smog and Pollution) "We work within the system in a responsible manner. We do not ask the impossible, but we demand compliance at the earliest possible moment within the state of the art of pollution control." I like the thought that pollution control is an "art".

If you don't feel you can organize groups, be available as a resource person to groups that are already organized. The Tiffin LWV efforts have benefited greatly from having resource persons who can obtain accurate, factual, unemotional information to be used in supporting our various positions.

A word about working with employees of governmental agencies. Remember that many of these people have many problems to concern themselves with besides just land use or environmental problems. Almost any problem has a financial aspect to consider. There are other pressure groups wishing that individual to see their side of the story.

I would like to leave you with these thoughts about the total picture of the river.

> I do not know much about gods; but I think that the
> river is a strong brown god --sullen, untamed, and
> intractable, Patient to some degree, at first recognized
> as a frontier; Useful, untrustworthy, as a conveyor of
> commerce; Then only a problem confronting the builder
> of bridges. The problem once solved, the brown god
> is almost forgotten by the dwellers in cities --ever,
> however, implacable, keeping his seasons and rages,
> destroyer, reminder of what men choose to forget.
> Unhonored, unpropitiated by worshippers of the machine,
> but waiting, watching and waiting.
>
> T. S. Eliot

EPILOGUE: SOME BRIEF REFLECTIONS ON THE SYMPOSIUM, THESE PROCEEDINGS, AND WATER QUALITY STUDIES IN THE SANDUSKY RIVER BASIN

DAVID B. BAKER

Heidelberg College, Tiffin, Ohio

The major goal of the symposium was to foster information exchange among the scientists engaged in water-related studies in the Basin and those involved in water quality management. With the publication of these proceedings, much information is now before us. However, the task of digesting, assimilating, and interpreting these data largely remains for the future. For the present, some preliminary observations and conclusions seem appropriate.

These proceedings contain detailed descriptions of the present-day Sandusky River and Bay areas as seen through the eyes of biologists, chemists, geologists, and hydrologists; and the information presented greatly augments the available base-line data. Generally speaking, as the data base increases through the kinds of surveys and detailed monitoring described in these proceedings, the research value of the data set also increases. But these data are of value not just for future reference, but for interpreting and studying present-day processes and relationships.

First of all, an expanded data base will allow more accurate assessments of water quality in the basin and the bay. This will facilitate the setting of priorities for pollution abatement programs. The expanded data base also

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allows a better assessment of the relative significance of various pollutant sources. Such knowledge is very useful in designing effective water quality management programs and assessing their efficiency. The data also can be used to recognize patterns and to study cause and effect relationships operating within the stream ecosystem.

In the future, our ability to distinguish between trends in water quality and "noise" associated with seasonal and annual variations will be limited by the extent of our base-line data. Given the cost of advanced waste treatment and of programs associated with agricultural pollution abatement and land-use controls, our ability to document water quality effects and benefits will be very important.

As our understanding of water quality and land-use relationships in the Sandusky Basin increases, the relevance of these studies to other river basins also should increase. The methods of studying nutrient transport developed in this basin already have proven useful in other studies, such as the Lake Erie Waste Water Management Study undertaken by the U.S. Army Corps of Engineers. In addition, the data sets available for material transport in the Sandusky Basin are being used to evaluate sampling strategies and calculation methods for use in tributary loading studies in Ontario, Canada.

An important product that has emerged from the examination of the data is a new set of questions which seem relevant for management decisions. Topics such as differential delivery ratios, pulsed-flow augmentation, integrated point and non-point source control programs, algal population dynamics in river systems are now being recognized as significant for present-day management programs.

It is worth noting that much of the data-base currently available from the Sandusky Basin has been produced in conjunction with the education programs at Heidelberg College and Bowling Green State University. The consequence of linking environmental research and monitoring to educational programs is that the research return research dollar investment can be very high. In addition, the research investment is accompanied by educational bonuses of considerable magnitude.

Several aspects of water quality research in the Sandusky Basin have intensified since the Symposium. It is our hope that these expanded studies will contribute to the improvement of water quality management programs within the basin and to the state of the art for river basin studies and water quality management in the Midwest. We hope, too, that educational institutions will have key rolls in these efforts of the next decade.

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